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LOW ENERGY STAGE STUDY

VOLUME IV

COST BENEFITS ANALYSIS AND RECOMMENDATIONS

FOR NASA
MARSHALL SPACE FLIGHT CENTER

 **VOUGHT
CORPORATION**
an LTV company



CHANGE SHEET

For

LOW ENERGY STAGE STUDY, VOLUME IV -
COST BENEFIT ANALYSIS AND RECOMMENDATION

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the margin.

FOREWORD

This \$236,000 Low Energy Stage Study was performed by Vought Corporation under NASA Contract NAS8-32710 for Marshall Space Flight Center from September 1977 through August 1978. The prime objective of the study was to determine the most cost effective approaches for placing automated payloads into low energy Earth orbits. These payloads are injected into circular or elliptical orbits of different inclinations with energy requirements in the range of capability between that of the Space Shuttle standard orbit altitude (296 km) and of the Shuttle with a Spinning Solid Upper Stage - D (SSUS-D). The study results are documented in five volumes:

- I. Executive Summary
- II. Requirements and Candidate Propulsion Modes
- III. Conceptual Design, Interface Analyses, Flight and Ground Operations
- IV. Cost Benefit Analysis and Recommendations
- V. Program Study Cost Elements and Appendices

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ABBREVIATIONS AND ACRONYMS

ACS	-	Attitude Control System
A/D	-	Analog to Digital
AGE	-	Aerospace Ground Equipment
AK	-	Apogee Kick
AKM	-	Apogee Kick Motor
AMPTE	-	Active Magneto Spinning Particle Tracer
ANT	-	Antenna
ASE	-	Airborne Support Equipment
BER	-	Bit Error Rate
BITE	-	Built-In Test Equipment
C&DH	-	Communication and Data Handling
CER	-	Cost Estimating Relationship
c.g.	-	Center of Gravity
CITE	-	Cargo Integrated Test Equipment
cm	-	Centimeter
CCR	-	Contracting Officers Representative
C/O	-	Checkout
C&W	-	Caution and Warning
CWE	-	Caution and Warning Electronics
db	-	Decibel
DDT&E	-	Design Development Test and Evaluation
DMU	-	Deployment Mechanism Unit
DOD	-	Department of Defense
DVT	-	Development Test
EDS	-	Empirical Data Sets
EED	-	Electro-explosive Device
EIRP	-	Effective Isotropic Radiated Power
ELV	-	Expendable Launch Vehicle
EMI	-	Electro-Magnetic Interference
ERBS	-	Earth Radiation Budget Satellite
ESH	-	Explosive Safe Area
ETR	-	Eastern Test Range
EVA	-	Extravehicular Activity
FSS	-	Flight Support System for MMS
GCU	-	Guidance and Control Unit
GHe	-	Gaseous Helium
GPC	-	General Purpose Computer
GPS	-	Global Positioning Satellite
GSE	-	Ground Support Equipment
GSFC	-	Goddard Space Flight Center
HMF	-	Hypergolic Maintenance Facility
Hz	-	Hertz (cycles)

ABBREVIATIONS AND ACRONYMS (CONT'D)

ICD	-	Interface Control Document
ICU	-	Ignition Control Unit
I/O	-	Input/Output
IRIG	-	Inter-Range Instrumentation Group
ISU	-	Inertial Stabilization Unit
IUS	-	Inertial Upper Stage
JSC	-	Johnson Space Center
Kbps	-	Kilo bits per second
Kg	-	Kilogram
KSC	-	Kennedy Space Center
km	-	Kilometers
Lbf	-	Pound-Force
Lbs	-	Pounds
L/D	-	Length/Diameter
LES	-	Low Energy Stage
LH	-	Left Hand
MCDS	-	Multifunction CRT Display System
MCEM	-	Mechanical Cost Evaluation Methodology
MDM	-	Multiplexer-Demultiplexer
MFBA	-	Mobile Flat Bed Assembly
MHz	-	Mega hertz
MLI	-	Multilayer Insulation
m	-	Meters
MMH	-	Monomethylhydrazine
MMS	-	Multimission Modular Spacecraft
MMSE	-	Multimission Support Equipment
mps	-	Meters per second
MSDP	-	Mission Station Distribution Panel
MSFC	-	Marshall Space Flight Center
N	-	Newtons
nm	-	Nautical Mile
NSI	-	NASA Standard Initiator
O&CF	-	Operations and Control Facility
OMS	-	Orbiter Maneuvering Subsystem
OPEN	-	Origin of Particles in the Earth Neighborhood
OPAF	-	Ordnance Payload Assembly Facility
OPF	-	Orbiter Processing Facility

ABBREVIATIONS AND ACRONYMS (CONT'D)

PCM	-	Pulse Code Modulation
PCR	-	Payload Changeout Room
PCU	-	Power Control Unit
PDI	-	Payload Data Interleaver
PGHM	-	Payload Ground Handling Mechanism
PK	-	Perigee Kick
PKM	-	Perigee Kick Motor
P/L	-	Payload
PRICE	-	Programmed Review of Information for Costing and Evaluation
PSDP	-	Payload Station Distribution Panel
PSI	-	Pressure Systems, Inc.
psi	-	Pounds per square inch
psig	-	Pounds per square inch, gage
RCS	-	Reaction Control System
RCVR	-	Receiver
RF	-	Radio Frequency
RFI	-	Radio Frequency Interference
RHCP	-	Right Hand Circular Polarization
RMS	-	Remote Manipulator System
R	-	Retrieval
rpm	-	Revolution per minute
SAEF	-	Spacecraft Assembly Encapsulating Facility
SCOOP	-	System Technology Office Confirmation of Optical Phenomenology
S/DIU	-	Signal/Data Interface Unit
SDP	-	Special Defense Program
Sec	-	Second
SIO	-	Serial Input/Output
SOP	-	Standard Operating Procedure
SPST	-	Single Pole Single Throw
SRB	-	Solid Rocket Booster
SRM	-	Solid Rocket Motor
SSUS-A	-	Spinning Solid Upper Stage - Atlas Class
SSUS-D	-	Spinning Solid Upper Stage - Delta Class
STDN	-	Space Tracking and Data Network
STS	-	Space Transportation System
TCD	-	Technical Characteristics Data
Td	-	The Time (months) to design and develop or produce a WBS item
TIG	-	Tungsten Inert Gas
TM	-	Telemetry

ABBREVIATIONS AND ACRONYMS (CONT'D)

TRS	-	Teleoperator Retrieval System
Ts	-	The Lead Time (months) measured from the start of cost accrued for the item to the launch milestone date, for the initial item
TSP	-	Twisted Shielded Pair
Tx	-	Transmitter
UARS	-	Upper Atmosphere Research Satellite
UDS	-	Universal Documentation System
VPF	-	Vertical Processing Facility
VPHD	-	Vertical Payload Handling Device
V	-	Revisit
WBS	-	Work Breakdown Structure
WTR	-	Western Test Range
ΔV	-	Delta Velocity

INTRODUCTION

This volume describes the work performed in Task 6, Cost/Benefits Analysis and Task 7, Recommendations. In Task 6 the cost/benefits of the new and existing/planned systems were derived and the lowest cost systems selected. In Task 7 the most cost effective approach was recommended along with the implementation plan to support NASA program decisions.

The report is contained in five volumes and organized as follows:

<u>VOLUME</u>	<u>TASKS</u>	<u>CONTENTS</u>
I	-	Executive Summary
II	1	Requirements Definition
	2	Candidate Propulsion Modes
III	3	Conceptual Design
	4	Interface Analysis
	5	Ground and Flight Operations
IV	6	Cost Benefit Analysis
	7	Recommendations
V	-	Program Study Cost Elements

A listing of references applicable throughout the report is included at the end of each volume.

7.0 TASK 6: COST/BENEFITS ANALYSIS

The costs and benefits of existing/planned systems from Task 2, new propulsion concepts and adaptations of existing/planned systems from Task 3 (as supported by Orbiter interface requirements from Task 4 and operations requirements from Task 5) were quantified. Scenarios of these propulsion approaches were established which accommodate the low energy regime as defined by the new low energy payload mission model (Volume III, paragraph 4.1). These scenarios were screened on a cost and then a benefits basis. A propulsion approach comprising existing/planned systems and a new propulsion concept were selected as the most cost effective approach to accommodate the model payloads and the low energy regime they represent. Key cost drivers and sensitivity trends were identified. All costs were derived in 1977 dollars.

7.1

PAYLOAD DELIVERY APPROACHES

The payload delivery approaches considered in the cost/benefits analysis include the existing/planned systems selected in Task 2 (Volume II), new propulsion concepts developed in Task 3 (Volume III) as well as adaptations of these propulsion concepts to existing/planned systems.

7.1.1

Existing/Planned Systems

The existing/planned propulsion systems selected in Task 2 as candidates to accommodate low energy payloads (Figure 7.1) include:

- Integral OMS and AS Kits
- Teleoperator Retrieval System
- Multimission Modular Spacecraft Propulsion Module (PM-II)
- Scout Expendable Launch Vehicle

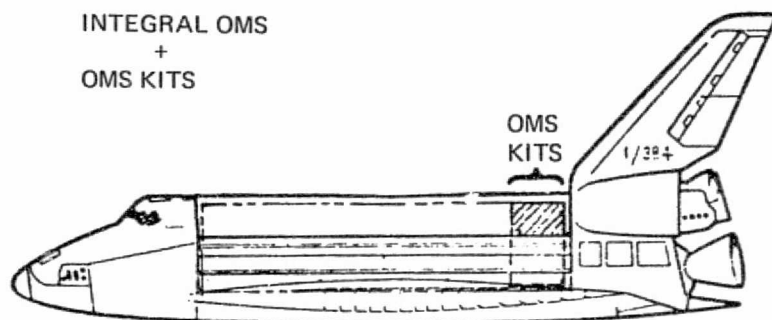
The mass, geometry, and performance of these systems used in this task reflect revisions (minor in most cases) from that used in Task 2 to account for system changes which occurred during the study.

7.1.1.1

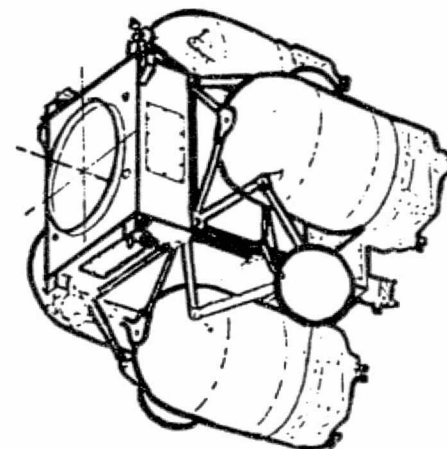
Integral OMS and OMS Kits - The integral OMS tanks are sized to deliver the Orbiter to altitudes above the standard 296 km (160 nm) altitude. This additional altitude capability (depicted in Reference 24) has been considered for delivery of observatory class payloads to their destination orbits since these payload lengths essentially dictate a dedicated Shuttle launch. Additionally, these payloads require extensive power-up, checkout, and verification of normal operation of many systems and experiments prior to orientation and deployment. Without other payloads aboard, the Orbiter can transfer to the destination altitude, deliver one of these payloads, and return to earth. Performance capability of the integral OMS (from Reference 24) shown in Figure 7.2 for ETR 28.5° launches, is greater than required by payloads 11 through 15 (defined in Volume III, paragraph 4.1), all of which are to be delivered from ETR into 28.5° orbits. Weight of ASE for mounting interface avionics and cabling to the payload was considered to be 91 kg (200 lbs.).

From one to three OMS delta-V kits (Reference 24), consisting of auxiliary propellant tanks of nitrogen tetroxide (N_2O_4) and monomethylhydrazine (MMH) will be available that provide the mass-velocity capabilities

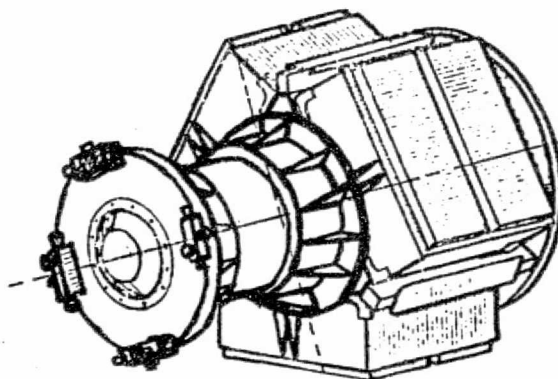
INTEGRAL OMS
+
OMS KITS



TELEOPERATOR RETRIEVAL SYSTEM



MULTIMISSION MODULAR SPACECRAFT
PLUS PROPULSION MODULE



SCOUT
EXPENDABLE
LAUNCH
VEHICLE



FIGURE 7.1 EXISTING/PLANNED LAUNCH APPROACHES

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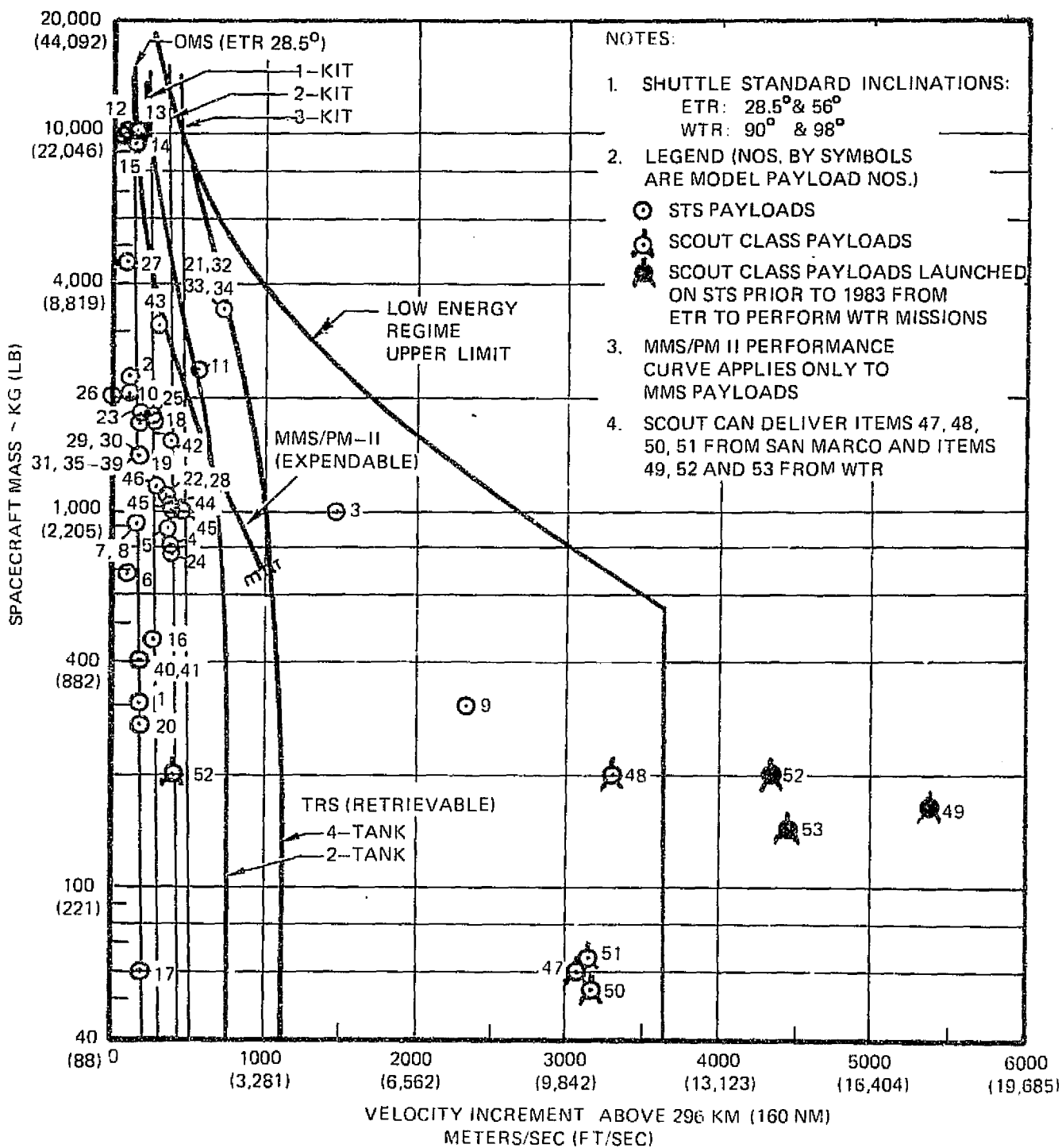


FIGURE 7.2 PERFORMANCE OF EXISTING/PLANNED PROPULSION SYSTEMS

shown in Figure 7.2 for launch from ETR into a 28.5° inclination orbit. Similar data (from Reference 24) are available for WTR launches. These OMS kit capabilities in conjunction with requirements of payloads of the LES model are used to establish the Shuttle shared-flight weight load factor, discussed in paragraph 7.2.1.6, rather than the Shuttle payload capability from Reference 22.

7.1.1.2 Teleoperator Retrieval System - The Teleoperator Retrieval System (TRS) is under development by NASA as a Skylab Boost System (Reference 19). A Spacecraft delivery version of the TRS (Figure 7.1), from Reference 45, has been considered as a LES candidate. Its performance capabilities in a retrievable mode in both a 2-tank and 4-tank configuration (Figure 7.2) were derived from the following mass, dimensional and performance data from References 45 and 27.

<u>CHARACTERISTIC</u>	<u>2-TANK</u>	<u>4-TANK</u>
Ignition Mass, kg(lb)	2718(5993)	4329(9543)
Useable Propellant Mass, kg(lb)	1352(2980)	2703(5960)
Effective Specific Impulse, sec	235	235
Length, m(ft)	2.13(7)	2.13(7)
ASE Mass, kg(lb)	1302(2870)	1302(2870)
ASE Length, m(ft)	2.23(7.33)	2.23(7.33)
ASE Diameter, m(ft)	4.52(14.83)	4.52(14.83)

Data shown for ASE are from the same reference. This ASE was designed to support the TRS alone and is not structurally adequate to support the TRS with a payload attached. Two alternatives were considered to provide the necessary payload support. The first was the use of the TRS ASE and one or two pallets as required to support the payloads. The second was the use of the weight and length characteristics of the LES ASE (Volume III, paragraph 5.1.2.1) to support both the TRS and the payloads. The second alternative was selected since it provided the shortest and lightest TRS payload installations. See Volume V, Appendix D for TRS ASE weights used in the cost/benefit analysis.

7.1.1.3 Multimission Modular Spacecraft - The larger propulsion module (PM-II) of the Multimission Modular Spacecraft (MMS) has been considered in

the study for only those payloads of the model specified to incorporate a MMS as part of the spacecraft. These payloads are defined in Volume III, paragraph 4.1. This payload assignment was made because the PM-II is dependent on the MMS for guidance and control, power and other functions. The PM-II performance capability in an expendable mode, shown in Figure 7-2, was derived from the following mass, dimensional and performance data taken from References 26 and 46.

Ignition Mass, kg (lb)	613 (1352)
Propellant Mass, kg (lb)	481 (1060)
Effective Specific Impulse, sec	220
Length, m (ft)	1.52 (5.0)
ASE Mass, kg (lb)	1905 (4200)
ASE Length, m (ft)	2.13 (4.7)
ASE Diameter, m (ft)	4.52 (14.83)

The performance capability shown in Figure 7.2, for the MMS-PM-II does not include 665 kg (1466 lbs.) for the mass of the MMS. The mass of payloads designated for MMS in the payload mission model (Volume III, paragraph 4.1), shown in the Figure, contains this 665 kg (1466 lbs.). The other payload masses do not; if PMII were considered for these payloads, the payload mass would have to be increased by 665 kg (1466 lbs.) for the MMS required to control the PM-II.

7.1.1.4 Scout Expendable Launch Vehicle - The Scout can deliver those payloads of the LES payload model designated as Scout payloads to the specified destination orbit. These payloads are launched from WTR for polar and sun synchronous orbits and from the San Marco launch site for 2.9° inclination orbits. A five-stage Scout is to be used for payload numbers 50 and 51 of the new LES payload model (Volume III, paragraph 4.1). Scout can also accommodate payload number 17. Performance capabilities of the Scout are from References 47 and 48.

7.1.2 New Propulsion Concepts and Adaptations of Existing Planned Systems

The new propulsion concepts, developed in Volume III, paragraph 4.0, consist of modular bipropellant and modular monopropellant LES systems.

In addition, this paragraph of the report presents the development of the applications of these concepts as delivery stages in conjunction with SSUS-D and SSUS-A as booster stages. These combinations are the adaptations of existing/planned systems considered. Volume III provides detail descriptions of the stage configurations for these new propulsion concepts and adaptations (paragraph 4.5), mass properties (paragraph 4.6), and performance capabilities (paragraph 4.7).

There are two families of modular bipropellant stages. The first modular concept consists of (1) an eight propellant tank horizontal arrangement; (2) a 4-tank horizontal version of this arrangement; and (3) a 4-tank vertical version of the 4-tank horizontal arrangement. The other modular family consists of a 4-tank and a 12-tank vertical arrangement. There are adaptations of the horizontal and vertical 4-tank versions of the first modular concept - each is adapted to the SSUS-A and the SSUS-D.

The modular monopropellant concept consists of (1) an eight propellant tank horizontal arrangement; (2) a 2-tank horizontal version of this arrangement; and (3) a 2-tank vertical version of the 2-tank horizontal arrangement. There are adaptations of the 2-tank vertical version to the SSUS-D and the SSUS-A.

7.2 QUANTIFICATION OF COST ELEMENTS

The development, production and operations costs for new propulsion concepts and adaptations, and the production and operations costs for existing/planned systems were determined.

7.2.1 Costing Philosophy

For any costing exercise dealing with multiple conceptual comparisons, which must be processed in a limited time, it is imperative that the costing technique be one of general application which can deal effectively with a large number of variables, yielding sufficient accuracy to produce meaningful results. It was initially evident that some form of parametric cost modeling technique would be most applicable to this circumstance. The use of more detailed cost estimating methods was limited to costing in the final phases of the study, when the number of alternatives had been reduced to a minimum, and sufficient time was available for this slower method. The Mechanized Cost Evaluation Methodology (MCEM), described in Task 2 (Volume III),

proved effective in preliminary evaluation and screening of propulsion approaches. When estimating costs in Task 2, it was necessary to use time saving methods to accelerate the screening process. First priority was given to the higher-cost portions of the designs, concentrating on the key differences in those areas which contribute to major cost impact. Much more attention was given to the cost of design differences than to the total system cost. Portions of the LES life cycle cost, which were determined to show minimum variance between design approaches, were placed in the "common" cost category and omitted from consideration. For this reason, during Task 2, costing work was deferred for several operational cost categories. A review of Table 7-I, LES Program Costing Elements, in paragraph 7.2.1.2, will show these areas.

As the initial screening of propulsion approaches was completed in Task 2, the emphasis shifted to a more detailed evaluation of the remaining approaches. In Tasks 3, 4, 5 and 6 concentrated effort was expended to increase the design definition and refine the costs. It was then possible to properly cost the operational areas, when quantities and types of equipments were set, and personnel requirements established for system operation. The greater definition then available made possible cost "detailing" to distinguish minor cost variations. In the final stage of the evaluation, total system cost assumed primary importance as the implementation costs for carrying the selected design approach into an operational status were determined.

7.2.1.1 Existing/Planned Systems - The costs for the existing/planned systems were requested from the agencies most responsible for this data. All data received was checked for accuracy to the extent possible, by comparison with reported contractual purchases, and in some instances through use of the MCEM routine. The costs, when verified, were adjusted to 1977 dollars using published Bureau of Labor Statistics data on industry wide wage compensation as adjustment criteria. These results are reflected in paragraph 7.2.2.

7.2.1.2 Work Breakdown Structure - The included Work Breakdown Structure chart, Figure 7.3, is the standardized format which has been used to itemize costs for all propulsion approaches. Each of the categories depicted on the chart are fully defined in Volume V, Appendix A. The costs of all new configurations are itemized according to this format and collected in Appendix C,

TABLE 7-I LES PROGRAM COSTING ELEMENTS

TASK		TASK 2									TASK 6										
WBS	STAGE PHASE	NEW			ADAPIONS			EXISTING			NEW			ADAPIONS			EXISTING				
		1-D	1-P	1-O	1-D	1-P	1-O	1-D	1-P	1-O	1-D	1-P	1-O	1-D	1-P	1-O	1-D	1-P	1-O		
LES PROGRAM	00-000	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	X		
LES PROJECT	10-000	X	X		X	X			X		X	X	X	X	X	X		X	X		
SPACE SHUTTLE	20-000			X			X			X			X			X			X		
USERS CHARGE	20-010			X			X			X			X			X			X		
ORBITER INTEGR'N	20-020												X			X			X		
PROJECT MGT.	10-0100	X	X	X	X	X	X			X	X ^a	X ^a	X	X ^a	X ^a	X			X		
LES VEHICLE	10-0200	X	X		X	X			X		X	X		X	X			X			
VEH INTEG'N & ASSY	10-0201	X	X		P	P					X	X		P	P						
BOOSTER STAGE	10-0210	X	X		P	P					X	X		P	P						
INTEG'N & ASSY	10-0211	X	X		P	P					X	X		P	P						
STRUCTURE	10-0212	X	X		P	P					X	X		P	P						
THERMAL	10-0213	X	X		P	P					X	X		P	P						
MAIN PROPULSION	10-0214	X	X		P	P					X	X		P	P						
DELIVERY STAGE	10-0220	X	X		P	P					X	X		P	P						
INTEG'N & ASSY	10-0221	X	X		P	P					X	X		P	P						
STRUCTURE	10-0222	X	X		P	P					X	X		P	P						
THERMAL	10-0223	X	X		P	P					X	X		P	P						
MAIN PROPULSION	10-0224	X	X		P	P					X	X		P	P						
RCS	10-0225	X	X		P	P					X	X		P	P						
DATA MGT/COM4	10-0226	X	X		P	P					X	X		P	P						
GAC	10-0227	X	X		P	P					X	X		P	P						
ELECT PWR	10-0228	X	X		P	P					X	X		P	P						
FACILITIES	10-0300										X			P							

LEGEND: X WILL BE COSTED
 P POTENTIAL COST-DEPENDENT ON CHANGES
 X^a INCLUDED IN SUBSYSTEM COSTS
 1-D DEVELOPMENT COSTS
 1-P PRODUCTION COSTS
 1-O OPERATIONS COSTS

TABLE 7-I LES PROGRAM COSTING ELEMENTS (CONCLUDED)

TASK		TASK 2									TASK 6										
WBS	STAGE	NEW			ADAPTIONS			EXISTING			NEW			ADAPTIONS			EXISTING				
		1-D	1-P	1-O	1-D	1-P	1-O	1-D	1-P	1-O	1-D	1-P	1-O	1-D	1-P	1-O	1-D	1-P	1-O		
SYSTEMS ENGRG & INTEG'N	10-0400	X	X	X	X	X	X		X	X	X	X ^a	X	X	X ^a	X		X	X		
LES SYS ENGRG	10-0401	X	X ^a	X	X	X	X			X	X ^a	X ^a	X	X	X ^a	X			X		
LES/ASE INTEG'N	10-0402			X			X			X	X		X	P ^b		X			X		
LES/PAYLOAD INTEG'N	10-0403			X			X			X			X			X			X		
SUSTAIN'G ENGRG	10-0404			X			X			X		X	X ^a		X ^a	X			X		
AIRBORNE SUPRT EQUIP'T	10-0500	X			X						X			P							
INTEG'N & ASSY	10-0501										X			P							
STRUCT & MECHANISM	10-0502										X			P							
AVIONICS	10-0503										X			P							
CONTROLS & DISPLAYS	10-0504										X			P							
SOFTWARE	10-0600										X			P							
SYSTEM TEST & EVAL	10-0700										X			X							
DEVELOPMENT	10-0701										X			X							
QUALIFICATION	10-0702										X			X							
MOCK-UPS	10-0703										X										
GROUND SUPPORT EQUIPMENT	10-0800										X			P							
CHECKOUT	10-0801										X			P							
ENDLG/ASSY & SERVICING	10-0802										X			P							
GROUND OPERATIONS	10-0900			X			X			X	X		X			X			X		
LOGISTICS/TRAINING	10-0901										X		X			X			X		
SPARES/REPAIR PARTS	10-0902			X			X			X			X			X			X		
FIELD SUPPORT	10-0903			X			X			X	X		X			X			X		
FLIGHT OPERATIONS	10-1000												X			X			X		

LEGEND: X^a INCLUDED IN SUBSYSTEM COSTS
 P^b INCLUDED IN 0201 AND 0501

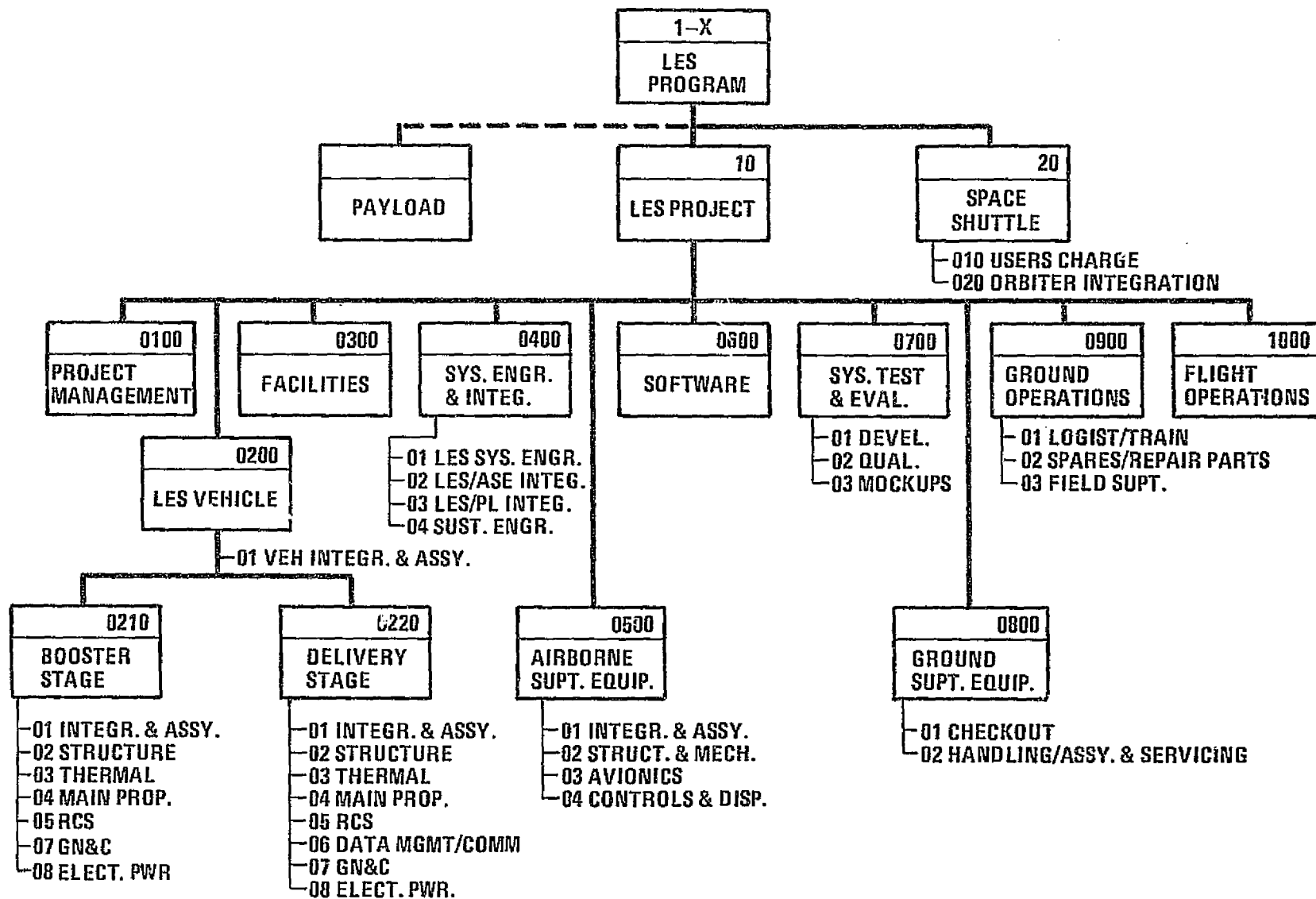


FIGURE 7.3 WORK BREAKDOWN STRUCTURE FOR LES STUDY

Volume V. The costs for certain purchased stages, such as SSUS-A and SSUS-D have been shown only to level 4 because of unavailability of detail data from the manufacturer. Table 7-I, LES Program Costing Elements, is a further subdivision of WBS elements into Development (DDT&E), Production and Operations phases for new stages, existing stages and adaptations to existing stages, and applies to the costing of Tasks 2 and 6.

7.2.1.3 Development Costs for New Concepts - The rationale used for estimation of Development (DDT&E) costs in Task 6 is the same used in Task 2, and is explained in Volume II, paragraph 3.3. Essentially stated, production costs are developed for each propulsion approach. The production cost is used in conjunction with general data, classification data, physical data and schedule data to develop relative complexity factors for use with the MCEM system. Table 7-II shows the data subelements considered. These factors were checked for validity and then used as the basis for estimating DDT&E costs. These costs were then subjected to comparative review by technical specialists with historical data for similar programs. Considerations of DDT&E commonality between similar configurations completed the estimate.

7.2.1.4 Production Costs - A considerable amount of detail data was gathered to estimate subsystem production costs. The complete sequence of the estimate is described in paragraph 7.2.3.1. The philosophy of production cost estimating was to develop typical cost models, determine their relative complexity and compare similar items to these basic models by comparison of their elemental data (Reference Table 7-II). Comparative review by technical specialists was the final step in this process. Costs developed were based on a quantity buy of 103 units during a ten (10) year period. Five production lots were assumed of approximately 20-21 units per lot. Volume II, paragraph 3.3.2 contains a description of the derivation of learning curves for subsystem items.

7.2.1.5 Operations Costs - Operations costs were developed in terms of annual (recurring) costs and unit (recurring) costs, for each site. Most of the costs in this category are for personnel, hence the basic philosophy was to concentrate on personnel requirements and to cost these cumulative hours in terms of grade level requirement and typical mark-up. Operational equipments are considered to be a part of DDT&E and have been estimated as described in paragraph 7.2.1.3.

TABLE 7-II

PRODUCT DESCRIPTORS SET
MECHANIZED COST EVALUATION METHODOLOGY

GENERAL DATA

- o Production Quantity
- o Prototype Quantity
- o Quantity/ System
- o Year of Estimate
- o Escalation Rate
- o Product Class (Reliability)
- o Markup Percentage (G&A and Fee)

CLASSIFICATION DATA

- o Percentage New Design
- o Engineering Complexity*
- o Manufacturing Complexity/Producibility*
- o Applicable Learning Curve
- o % Structural/% Electronic
- o Percentage Redundancy
- o Integration Classification
- o Degree of change traffic, Project Management, Documentation, Systems Engineering, tools and test equipment (For items requiring special treatment)

PHYSICAL DATA

A. Structural/Mechanical

- o Structural weight
- o Structural volume
- o Material type
- o Structural class
- o Fabrication type

B. Electronics

- o Electronics weight
- o Electronics volume
- o Equipment class (type)
- o Sub-component technology (type)
- o Component count
- o Dissipated power

SCHEDULE DATA

- o Design Program Length
- o Test Program Length
- o Production Program Length

*Note: Item cost may be used, together with associated data to develop complexity data.

7.2.1.6 Shuttle Charges - A significant majority of the payloads in the LES mission model are in the Shuttle user categories of civil agencies of the U.S. Government or participating foreign government users as defined in Reference 22. The standard transportation charge for a dedicated Shuttle flight to these users is \$18.00M in 1975\$ (References 22 and 49). Escalation to 1977\$ in accordance with Reference 49 increases this charge to \$21.834M. With the exception of the very long payloads which are candidates for integral OMS delivery, the payloads in the LES model do not require an entire Shuttle flight capability and thus are considered for shared-flight charges. Shared-flight load factor is the greater value of either (1) Orbiter payload length (includes spacecraft, delivery stage and ASE) plus .152 m (0.5 ft.), for clearance, divided by the length of the cargo bay, 18.288 m (60 ft.); or (2) Orbiter payload weight divided by the total Shuttle payload weight capability for the Shuttle standard inclinations (References 22 and 23). These inclinations are 28.5° and 56° from ETR and 90° and 98° from WTR, refer to Volume III, paragraph 4.1.3. Cost factor, the shared-flight load factor divided by 0.75, is multiplied by the dedicated Shuttle flight charge of \$21.834M to determine the shared-flight charge. This charge is also applicable to OMS kits. The Shuttle user charge was determined as shown in Volume II, Table 3-XXI. The installed weight and length of the payload, stage and ASE were used in calculating the charges. The charge for horizontal installations was apportioned to the payload and to the stage + ASE on the basis of weight for weight critical installations and on the basis of length for length critical installations. For vertical installations the charge was apportioned on the basis of weight for weight critical installations. For length critical vertical installations the charge was apportioned to the payload on the basis of the payload diameter and to the stage + ASE for any cargo bay length required over and above the payload diameter.

7.2.2 Costs of Existing/Planned Systems

The costs of existing/planned propulsion systems considered in the LES study were obtained from NASA documents or from cognizant NASA personnel.

7.2.2.1 Integral OMS and OMS Kits Costs - In addition to the Shuttle shared-flight charge, an additional charge is planned for Orbiter delivery of

a payload to a non-standard orbit altitude; i.e., other than 296 km (160 nm). An estimated charge of \$0.2M for this service, used in the study, was obtained from cognizant NASA Headquarters personnel. In addition to the Shuttle shared-flight charge there are optional flight system charges for OMS kits. These charges, use cost and serial impact cost, are from Reference 32 and are summarized in Table 7-III along with dimensions and mass necessary to compute shared-flight charge.

TABLE 7-III
ORBITER MANEUVERING SUBSYSTEM KIT COSTS

NUMBER OF KITS	LENGTH m (ft)	MASS kg (lb)	USE COST 1977\$	SERIAL IMPACT	
				TIME-HR	COST-1977\$
1	2.745 (9)	7401 (16302)	266,295	20	333,580
2	2.745 (9)	13379 (29468)	532,590	64	1,067,456
3	2.745 (9)	19537 (43033)	798,858	108	1,801,332

7.2.2.2 Teleoperator Retrieval System Costs - TRS development costs and the cost of one TRS were considered funded by the Skylab Boost Program. This TRS was considered to be used at ETR. Two additional TRS with ASE were assumed purchased at \$11M each in 1977\$ (in accordance with Reference 50); one in 1982 for use at WTR and one in 1983 as a backup. All three TRS were considered available for uses other than the low energy payload program. Retrieval (References 23 and 32) and refurbishment costs of the TRS (Reference 23) in 1977\$ are:

	<u>2-TANK</u>	<u>4-TANK</u>
Retrieval Cost	0.364M	0.364M
Refurbish Cost	0.175M	0.250M

Unit, annual and launch site dependent operations costs used for TRS are the same as those used for other low energy stage candidates (paragraph 7.2.3.3).

7.2.2.3 Multimission Modular Spacecraft PM-II Costs - PM-II and ASE development costs were considered funded by the MMS program. Expendable PM-II production cost used in the study was \$0.977M in 1977\$ (Reference 51). Unit,

annual and launch site dependent operations costs used for PM-II are the same as those used for other low energy stage candidates.

7.2.2.4 Scout Expendable Launch Vehicle Costs - The costs of the four-stage Scout launch vehicle used in the study, taken from Reference 52 are:

Unit Costs in 1977\$

WTR Launch \$3.817M

San Marco Launch 4.817M (For non-Italian Payload)

Additional cost for a fifth stage is \$0.5M

Annual program maintenance costs (Reference 52) which include all Scout program costs other than the unit costs are \$4.811M in 1977\$.

7.2.3 Costs of New Propulsion Concepts

Costs were developed for the categories of (1) Production, (2) Development (DDP&E), and (3) Operations. The developed cost information is contained in Appendix C of Volume V.

7.2.3.1 Production Costs - Production costs are a composite of recurring material, production (manufacturing) labor and quality control coverage, together with production (sustaining) engineering. All production costs were derived with appropriate additions for general administrative overhead and profit margins added to each item at the subsystem level 5, to give selling prices. Costs are shown in 1977 calendar year dollars. The basic approach used in the development of production costs was an extension of the methods used to develop costs in Task 2. The primary difference being the greater amount of configuration definition and specific knowledge of the design available in this phase of the study, and the reduced number of configurations subject to review. The greater amount of time available to study each configuration enabled a more comprehensive evaluation of each propulsion approach. Selected subsystems of the low energy stage were analyzed by detail estimate. Those given foremost attention were the high cost areas, such as the propulsion subsystem and electronic equipment. Equipment lists were composed for these selected parts of the LES in Task 2 as a detail check on the accuracy of the parametric estimates. Equipment lists were refined as alternative vendor sources were investigated for selection of applicable equipment types. Budgetary quotations were then solicited for the foremost equipment items.

Alternative quotations were requested when the first quotations received were considered questionable because of price or application. All quotations for equipment items were reviewed by technical specialists in comparison with accumulated historic data for similar hardware. These subsystems component lists were then reviewed for structural and electronic integration and test characteristics. Each component was assigned an integration value rating based on its relative integration complexity. These data, together with physical information for subsystem components provided the basis for installation cost estimates, by means of the Mechanized Cost Evaluation Methodology (MCEM) previously described. These labor estimates were then spot checked for accuracy by comparison with independently derived manufacturing estimates.

The material and manufacturing labor cost for each subsystem was then processed through a MCEM subroutine, described in Volume II, paragraph 3.3.1, to develop subsystem complexity factors for design and manufacturing. These data were directly compared with other complexity factors developed for a wide array of similar product groups. The MCEM system data bank contains an extensive catalog of complexity factor data which has been derived during thirteen (13) years of system use and reflects many thousands of cost studies. Virtually every type of hardware component and system has been cataloged and is available for comparisons of this type. Once consistent correlations are obtained, and variations from the norm explained, the basic data is authenticated for further use and filed in this company's data banks. All production costs for new design configurations were based on cumulative average for 103 units, produced in five lots over a ten (10) year period, assuming 20-21 items per lot. The learning curve used was a 95% Wright slope. Production quantities for the new design configuration portion of Task 6 scenarios, ranged from 78 items to 112 items, with the preponderance being at the larger quantity. A weighted average of all scenario configurations studied would give approximately 107 items, however, the lowest cost scenarios were C-1 and C-2, both of which used the 103 new design quantity. For this reason a 103 item quantity was selected as the typical near average production quantity for the comparison study. A development of the production plan and applicable learning curve is contained in Volume II, Table 7-IV and in Volume V, paragraph 3.3.

Three typical production cost summaries are shown in Table 7-IV for four-tank and eight-tank bipropellant propulsion stages. The subsystems

18

[illegible]

19

[illegible]

20

[illegible]

components for all three versions of this modular system are identical with the exception of propellant and pressurization line length, electrical harness length, and thermal insulating blanket size. The structure is modular, for example the central core that supports the subsystem components is common to all configurations as is the tankage support modules. See Volume III, paragraph 4.5.1 for a more detailed description of the structure and Volume V, paragraph 1.2.3 for a description of the systems costing commonality.

T_d is the estimated schedule time in months to design and develop (DDT&E) and produce the initial item. T_s is the estimated lead time in number of months from start of cost accrual, for the initial item, to the launch milestone date. A more detailed discussion of this data is presented in Volume V, paragraph 3.1.

7.2.3.2 Development Costs - Actions to this point were directed at establishing the LES vehicle subsystem recurring costs and relating them in terms of relative complexity to other similar subsystems in the historical data file. Placing the subsystems in this context was important because it established a frame of reference where not only recurring production costs were comparable, but non-recurring design, development, test and evaluation costs were comparable as well. In essence, considerable effort was expended by detail cost buildup and repeated comparison to develop an accurate production cost, and to place it in context with other similar assemblies or subsystems verifying its relative complexity. By confirming its correct relative complexity, the estimating of the DDT&E costs was simplified.

Based on the subsystem descriptive parameters, and other data described in Volume II, paragraph 3.3.1, and the developed complexity factors, it was possible to predict the DDT&E cost for new designs within reasonable accuracy. All DDT&E cost was developed to include separate estimates for design and drafting, systems engineering, project management, data, tooling/test equipment, and prototype buildup. The final step in estimation of development costs was the review by technical specialists in each area of responsibility. This review was a personal comparison of the MCEM subroutine results with personal and historic data available to the specialist. Differences in the data were subsequently resolved before the costs were used in the study. At this time the costs represented separate configurations,

as if each configuration were developed as a separate program. The configuration costs were then integrated with associated configurations to develop scenario cost as defined in paragraph 7.4.2. Integration of configuration costs to develop scenario costs was primarily a process of developing commonality of design. Substantial commonality exists between configurations of type. For example, the new propulsion approach portion of Scenario C-2 consisted of a set of modular bipropellant configurations of four (4) and eight (8) tank design, for both horizontal and vertical installations. These designs were essentially common and produced on a single production line, where the effects of "learning" were maximized. This situation could be compared to an automotive production line where a certain size automobile is produced having minor differences in accessories and subsystems. For versions of the bipropellant stage system all subsystem components are identical with the exception of the propellant and pressurization line lengths, electrical harness lengths, and thermal insulating blanket size. The structure is modular, for example the central core that supports the active system is common to all configurations as in the tankage support modules. See Volume III, paragraph 4.5.1 for a more detailed description of the structure and Volume V, paragraph 1.2.3 for a description of the system costing commonality. The DDT&E cost is substantially reduced from the overall total by omission of common costs, but is significantly greater than that cost for any given version. An example of a typical vehicle stage scenario DDT&E cost summary is shown as part 10-0200 of Table 7-V. Volume V, Appendix C includes cost summaries for all stage scenarios investigated.

Facilities - The study did not develop a requirement for new or modifications to facilities, hence this cost category was omitted.

Airborne Support Equipment - Development of the cost for Airborne Support Equipment (ASE) presented a different problem from most other categories of the Low Energy Stage. The problem was that there were few other items which could serve as a fully adequate cost model. Initial effort was expended to collect current cost information for ASE items presented in design. Secondly, previous estimates of ASE for other NASA and Vought programs were reviewed for applicability (similarity) to the design approach depicted in Volume III, paragraph 5.1. Lastly, a research of historical complexity data on file for other space structures of construction similarity was undertaken.

TABLE 7-V
NON-RECURRING DDT&E
MODULAR BIPROPELLANT SYSTEM

WBS CODE	WBS IDENTIFICATION	WBS LEVEL	NO. OF PROTS	COSTS IN 1000'S OF \$		T _d	T _s
				TOTAL	AVG. UNIT		
10-0100	Project Management	4	---	(100)	N/A	20	33
10-0200	LES Vehicle	4	N/A	(14,319)	N/A	20	33
10-0201	Vehicle Integration and Assembly	5	---	---		---	---
10-0210	Booster Stage	5	---	---		---	---
10-0220	Delivery Stage	5	1	14,319		20	33
10-0221	Integration & Assembly-Delivery Stage	5	1	737		20	33
10-0222	Structure and Mechanism	5	1	2,241		16	33
10-0223	Thermal System	5	1	164		6	33
10-0224	Main Propulsion	5	2	6,564		20	33
10-0225	Reaction Control System	5	2	750		20	33
10-0226	Data Management & Communications	5	2	19		7	9
10-0227	Guidance Navigation and Control	5	2	3,111		12	24
10-0228	Electrical Power System	5	2	733		18	26
10-0300	Facilities	4	---	---		---	---
10-0400	LES Systems Engrg-LES/ASE Integr	4	---	(172)	N/A	20	33

TABLE 7-V
NON-RECURRING DDT&E
MODULAR BIPROPELLANT SYSTEM

WBS CODE	WBS IDENTIFICATION	WBS LEVEL	NO. OF UNITS	COSTS IN 1000'S OF \$		T _d	T _s
				TOTAL	AVG. UNIT		
10-0500	Airborne Support Equipment	4	3	(5,371)	N/A	12	17
10-0501	Integration and Test	5	3	116		12	17
10-0502	Structure and Mechanisms	5	3	4,811		12	15
10-0503	Avionics - ASE	5	3	201		10	13
10-0504	Controls and Displays	5	3	243		10	14
10-0600	Software	4	1	(570)	N/A	20	24
10-0700	System Test and Evaluation	4	N/A	(1,427)	N/A	12	24
10-0701	Development	5	-	1,004		12	24
10-0702	Qualification	5	-	303		12	24
10-0703	Mock-ups	5	1	120		10	15
10-0800	Ground Support Equipment	4	N/A	(3,950)	N/A	20	26
10-0801	Checkout	5	-	2,036		20	26
10-0802	Handling/Assembly/Servicing	5	-	1,914		20	26
10-0900	Ground Operations	4	N/A	(195)	N/A	12	18
10-0901	Logistics/Training	5	-	91		12	18
10-0903	Field Support	5	-	104		10	13

The model of greatest similarity to the LES ASE was considered to be the ASE for the Multimission Modular Spacecraft (MMS), currently in design. Estimated (projected) costs for this design were given by Reference 46 for the MMS retention system, payload positioning system and the FSS interface electronics. This information, together with collected physical data (weights, volumes, material, etc.) was evaluated by processing it by use of the MCEM. Complexity factors for (1) manufacturing, (2) engineering design and (3) producibility were developed which, in turn, were compared with historical complexity data currently on file for other space vehicle structures. In addition, a manufacturing detail estimate was prepared to serve as a third cost reference for ASE structures. The complexity results indicated MMS ASE of highest manufacturing complexity (7.198), the space structure historical data as somewhat lower complexity (6.100) and the detail manufacturing estimate as falling between the two (6.579). Additional historical data examples showed large space structures to fall very close to the complexity value of 6.1. Design comparison between the MMS-ASE design and the LES-ASE design showed LES-ASE somewhat less complex and therefore logical in results on the low side. The Vought manufacturing detail estimate complexity tended to confirm the historical data as applicable to the ASE, hence a 6.1 complexity cost factor was used as firm cost data and most likely value. The relative complexity developed for the ASE cradle was used to estimate DDT&E cost. These costs were subjected to final review for validity by assigned technical specialists. See Volume V, paragraph 1.4.2 for a discussion of complexity cost factor derivation.

ASE Avionics is composed of the signal/data interface unit, power control unit, deployment mechanism unit and associated cable harnesses. The ASE controls and display category comprises the control and monitor panel and umbilical cable. All items of avionics, controls and display were estimated separately by comparison analysis of contents and application of the MCEM. Complexity factors were developed for each equipment item, based on overall size and total weight, electronics volume, structural weight, electronics density, equipment type (analog, digital, etc.), component type (semiconductors, integrated circuits, LSI, hybrid, etc.), percentage new design, design redundancy, power dissipated, component count, and design and production schedule. The complexity factors developed were again compared with factors for similar equipments, as a check on credibility of data. DDT&E costs were

derived by use of these data and were reviewed by technical specialists familiar with these equipments.

By means of integration classification, values assigned to each equipment item and to the components of the modular-cradle, an integration DDT&E cost was derived for the total ASE package.

Software - All software costs were developed by comparison projection from similar software selected for the Scout Phase VIII guidance system. The selection of this system as a cost model is explained in Volume III, paragraph 4.2.4. The cost of this system is based on actual expenditures to date and estimates to completion. The cost includes vendor test software, contractor test software and flight software.

System Test and Evaluation - This category includes the cost to plan and perform integrated system level tests on the LES vehicle and perform major element Interface Tests. All test costs included here were derived by detail buildup and by comparison with previous programs. The primary costs included for the development subelement are propulsion and structural tests. Qualification subelement testing included here is for the propulsion system. Rationale for the structural testing is shown in Volume III, paragraph 4.2.2. The propulsion testing discussion is contained in Volume III, paragraph 4.3. Additionally, the cost for a mockup of both delivery stage and ASE cradle is included as an evaluation tool. Cost for the mockup was prepared by detail estimate. See Volume V, Appendix A for system test and evaluation costs.

Operations DDT&E - One significant difference between the costing accomplished in Task 2 and the costs developed in Task 6 is the addition of DDT&E costs for the operations categories, WBS 10-800 Ground Support Equipment and 10-900 Ground Operations. Ground Support Equipment DDT&E cost is the non-recurring expense associated with the design and production of the category 10-801 test equipments and 10-802 handling devices required for field operations. Estimation of costs in this area were accomplished for each equipment item by comparison with similar equipment items from other programs. Scout Launch Vehicle equipments were the base comparison models in many areas. The Mechanized Cost Estimation Methodology was again used to check the more costly electronic and control devices.

7.2.3.3 Operations Costs - Operations costs are those elements of recurring cost which are expended throughout the operational life cycle of the system, which insure successful functioning of the system. The non-recurring costs associated with these operational elements are part of DDT&E cost for the system. Operational costs are made up of those elements which recur per launch, and those costs which are constant and applied on an annual basis at each launch site. The operational costs which have been derived for the LES Program are shown in Table 7-VI, with the exception of the Space Shuttle Users Charge. The User's Charge is stage, payload and mission dependent and therefore does not continuously recur as other operational costs. It is shown as a separate entry on the final summary page. A discussion of this entry is contained in paragraph 7.4 with an example of a typical summary sheet.

Operational costs were developed principally by a detail estimation approach. Field personnel requirements were estimated using the field processing flow defined in Volume III, Figure 6.4 and the critical path requirements of Volume III, Figure 6.5. These estimates were fully consistent with Scout experience. A discussion of operational requirements and operating procedures defining the groundrules and assumptions is contained in Volume III, paragraph 6.1.6. All operational equipments were estimated by item and the combined total included in the DDT&E cost. A breakdown of operations costs are contained in the following WBS elements; Orbiter-Integration, Systems Engineering, LES/ASE Integration, LES/Payload Integration, Sustaining Engineering, Logistics/Training, Spares/Repair Parts, Field Support and Flight Operations. In addition, the Program Management element contains Project Management office expense for maintaining the program. Operational recurring costs are applied in the study on a per vehicle basis. The annual operational expense is prorated against the total number of launches which occur and therefore will vary according to the total number required per LES program.

7.2.4 Costs of Adaptations of Existing/Planned Systems

7.2.4.1 Booster Stage - The Booster Stages developed in Task 2 were screened to eliminate all except the SSUS-A and SSUS-D types for Task 6. These boosters were considered purchased as complete assemblies, and delivered directly to the launch site preparation area for joining with the Delivery Stage. The details of use for these boosters is contained in Reference 39.

TABLE 7-VI
FOR OPERATIONS
MODULAR BIPROPELLANT SYSTEM

WBS CODE	WBS IDENTIFICATION	WBS LEVEL	NO. OF UNITS	COSTS IN 1000'S OF \$		T _d	T _s
				TOTAL	AVG. UNIT		
20-0000	Space Shuttle	43	103	N/A	N/A		
20-0100	User's Charge-Cost/Launch	4	103	*	*		
20-0200	Orbiter Integration -						
	Cost/Launch	4	103	(1,854)	(18)		
10-0100	Project Management -						
	Annual Cost	4	10	(5,000)	(500.0)		
10-0400	System Engineering and Integration	1					
	Cost/Launch		103	(14,781)	(143.5)		
	Annual Cost		10	(5,800)	(580.0)		
10-0401	LES Systems Engineering	5					
	Cost/Launch		103	11,279	109.5		
	Annual Cost		10	3,800	380.0		
10-0402	LES/ASE Integration						
	Cost/Launch	5	103	1,751	17.0		
10-0403	LES/Payload Integration						
	Cost/Launch	5	103	1,751	17.0		
10-0404	Sustaining Engineering						
	Annual Cost	6	10	2,000	200.0		
*NOTE	User's Charge is stage, payload, and mission dependent. See Form 5.						

TABLE 7-VI
FOR OPERATIONS
MODULAR BI-PROPELLANT SYSTEM

WBS CODE	WBS IDENTIFICATION	WBS LEVEL	NO. OF UNITS	COSTS IN 1000'S OF \$		T _d	T _s
				TOTAL	AVG. UNIT		
10-0900	Ground Operations -						
	Cost/Launch	4	103	(15,059)	(146.2)		
	Annual Cost	4	10	(11,733)	(1,173.3)		
10-0901	Logistics/Training -						
	Cost/Launch	5	103	927	9.0		
10-0902	Spares/Repair Parts						
	Cost/Launch	5	103	2,575	25.0		
10-0903	Field Support	5					
	Cost/Launch		103	11,557	112.2		
	Annual Cost (Prior to 1983)		1	617.5	617.5		
	Annual Cost (1983 and Sub)		9	11,115	1,235.0		
10-1000	Flight Operations						
	Cost/Launch	4	103	(309)	(3)		

Costs for SSUS-A and SSUS-D were obtained from Reference 53. These estimates were given in 1975 dollars as (not to exceed) costs to launch using (1) SSUS-D \$2M, and (2) SSUS-A \$3M. These costs were adjusted to 1977 dollars using the same projection factor criteria as used earlier for the Shuttle Users Charge to be (1) SSUS-D \$2.426M, and (2) SSUS-A \$3.639M. Costs include hardware and baseline mission analysis and services. Baseline mission analysis and services including hardware acceptance testing, hardware pre-ship review, mission readiness, safety analysis, motor target adjust analysis, launch preparation documents, launch site operations, post-flight analysis, support of the launch site, program management, scheduling, countdown procedure inputs and component temperature review.

Additional mission specific analyses and services charges were included for launch applications using the SSUS-A or D alone as the delivery stage. Mission specific analyses and services consist of: (1) mission oriented analysis such as dynamic stability analysis and thermal analysis, (2) launch oriented services such as spacecraft integration and launch realtime support. These charges, in 1977 dollars, are in addition to baseline charges and were estimated for SSUS-A or D to be:

- Mission Oriented Analyses - \$.75M
- Launch Oriented Services - \$.45M

7.2.4.2 Delivery Stage - The boosters previously discussed have been added to certain selected LES stages to accomplish special mission objectives. These stages are (1) the 4-tank vertical bipropellant stage, (2) the 4-tank horizontal bipropellant stage, (3) the 2-tank vertical monopropellant stage, and (4) the 2-tank horizontal monopropellant stage. When an existing stage is used with attaching booster, minor additions are made to the stage's structure to adapt it to interface with the booster. In like manner, the reaction control system was enlarged to adjust for and counteract the additional mass added to the stage. These additional parts/components have been accounted for by additions to the cost in each category. In addition, the modified stages with attaching boosters were redesignated to identify the configuration type. The recurring (production) stage cost and DDT&E costs were estimated by treating these configuration modifications as separate new designs and costing them in the same manner as described in paragraphs 7.2.3.1 and 7.2.3.2.

7.3

SENSITIVITY CONSIDERATIONS

Total system cost for any new launch approach is the sum of development cost, production cost and operations cost. For a typical new propulsion approach, as shown in the following paragraphs (C-2 of Figure 7.6), the costs without the payload user charges are distributed as follows:

- Development Cost (5%)
- Production Cost (36%)
- Operations Cost (59%)
 - Stage Users Charge 37%
 - Operations Support 22%

The operations cost is the single highest cost category, with the Shuttle users charge for the stage being the major element of this category. Operations support, although a costly element, was essentially non-variable and relatively unaffected by stage design.

The Shuttle user charge for the stage was a function of the user charge policy, Reference 11. The sensitivity of the charge to stage length and weight variation based on a dedicated launch cost of \$21.834M was as follows:

<u>CONDITION</u>	<u>DELTA SHUTTLE USER CHARGE (DOLLARS)</u>
• Weight Critical Installations	
Delta Stage Weight = .45 kg (1 lb)	
28.5° Inclination Launch	448
56° Inclination Launch	511
90° Inclination Launch	787
98° Inclination Launch	882
• Length Critical Installations	
Delta Stage Length = 2.54 cm (1 inch)	40433

The Shuttle user charge policy drives the stage and payload length toward the shortest installation possible with the desired weight to length ratio less than 818 kg/m (550 lb/ft) as discussed in paragraph 8.3 of

this volume. For the bipropellant modular stage propulsion approach 80 percent of the cargo bay installations were length critical. A relationship was also found to exist between stage inert weight and stage length for these length critical installations. This resulted in a sensitivity of 160 dollars of user cost for an increase of .45 kg (1 lb) of inert weight.

With 80 percent of the installations length critical, and a user charge of 40433 dollars per 2.5 cm (1 inch), length was the predominant driver for the Shuttle user charge for the stage.

Production cost was found to be significantly affected by stage design complexity; system equipment cost being the most costly element of production cost. The cost of selected qualified equipments tended to drive production costs.

7.4 COST/BENEFITS

Cost comparisons of existing/planned systems and new propulsion concepts were made by combining the development, unit, and operations costs derived in paragraph 7.2 with the Shuttle user charge to determine the life cycle cost to launch the payloads of the mission model.

7.4.1 Selection Methodology

The methodology used to evaluate and select the lowest cost propulsion approach is shown in Figure 7.4. The comparative evaluation of different combinations of propulsion approaches was accomplished by the use of logical groupings, or scenarios, each of which have equal capability to handle the entire mission model. Each scenario defines a propulsion approach to launch each payload. Using the conceptual design of Task 3 as supported by the ASE and flight operations from Tasks 4 and 5, logical scenarios were selected for the bipropellant and monopropellant propulsion approaches. Development, production and operation costs were derived for each approach and the scenarios stacked in order of increasing costs. The cost/benefits and other benefits of the two propulsion approaches were evaluated and the best new propulsion approach selected.

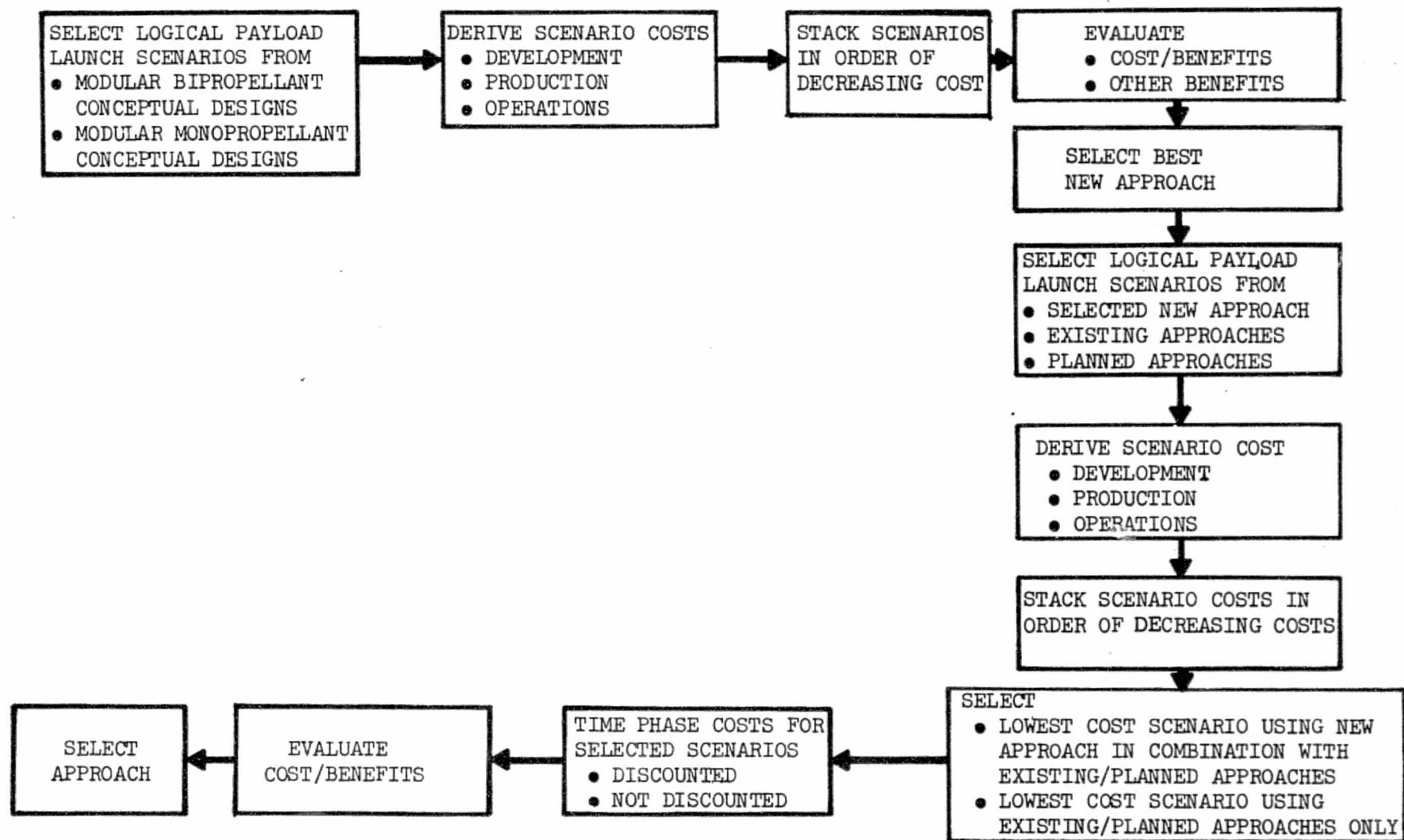


FIGURE 7.4 SELECTION METHODOLOGY

Scenarios were then selected to launch the mission model payloads using the selected new approach in combination with existing planned approaches. As a basis for comparison, scenarios were also selected using only existing/planned approaches. Again development, production and operations costs were derived and the scenarios stacked in order of increasing cost. The lowest cost scenario using the new propulsion approach in combination with existing/planned and the lowest cost scenario using only existing/planned approaches were selected from this cost stacking.

The costs for these two scenarios were time phased by year to match the launch date for each payload and the cumulative costs plotted versus year in 1977 dollars discounted and not discounted. The cost/benefits of the two scenarios were evaluated and the lowest cost propulsion approach selected.

7.4.2 Scenario Development

The 129 payloads defined in Volume III, Table 4-IV, were assembled into 30 groups with common or near common orbit inclination, launch inclination, sizes, weights and velocity change requirements as shown in Table 7-VII. The payloads that include the MMS bus are coded with an M. The PM-II was considered as a candidate propulsion approach for these payloads. The payloads that are coded with a V are short and were considered candidates for vertical launch from the Orbiter.

Tables 7-VIII and 7-IX are typical examples of the scenarios that were selected to screen and select one of the two new approaches. In these scenarios only the integral OMS, modular bipropellant or modular monopropellant or adaptations of SSUS-A and SSUS-D were used to launch the payloads of the model. A summary of all scenarios examined is presented in Volume V, Appendix C. For the comparative analysis of new approaches 128 of the 129 payloads were used. Payload 49 was not used in these scenarios because it is currently

TABLE 7-VII PAYLOAD GROUPING

PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS	CODE	NUMBER OF PAYLOADS	PAYLOAD* INCL. DEG.	LAUNCH* INCL. DEG.	PAYLOAD* SIZE L/D (M)	PAYLOAD* WEIGHT (KG)
1	12		6	28.5	28.5	7.3x4.3	10000
2 (1)	13,14,15		10	28.5	28.5	13 x4.6	9743
3	27		3	28.5	28.5	3.6x2.8	4500
4	43		1	98.5	98	9 x 4	3110
5	21,32,33,34	M	10	85	90	8 x 3	3400
6	11	M	1	52	56	5 x 4	2400
7 (1)	2		4	28.5	28.5	4.6x4.6	2270
8	10	M	4	28.5	28.5	4 x2.2	2047
9	23	M	3	56	56	5.2x2.3	1800
10	18,25,29-31,35-39	M	18	97.8	98	4.4x2.2	1700
11	19,42		3	99.1	98	4.2x1.6	1482
12	22,28,44,46		19	99.1	98	6.7x3	1150
13	3		2	44.9	56	1.8x1.4	1000
14	45		6	28.5	28.5	1.0x4.0	1000
	45		6	99.5	98	1.0x4.0	1000
15	7,8		3	90	90	3.6x2.2	910
16	5,24	V	4	99.1	98	2.8x1.5	836
17	4		3	99	98	2.9x4.4	816
18	6,40	V	4	90	90	1.7x1.3	540
19	16		1	56	56	4.3x2.1	454
20	41	V	3	28.5	28.5	1.5x1.2	400
21 (1)	1		1	28.5	28.5	.9x4.6	310
22 (1)	9		1	90	90	3 x4.6	300
23	20	V	1	99.2	98	.9x .9	270
24	52	V	1	90	90	1.5x .8	200
25	52		3	90	56	1.5x .8	200
26	48	V	1	2.9	28.5	1.5x .8	200
27	49	V	1	97	56	1.5x .8	165
28	53	V	2	90	56	1.5x .8	145
29	47,51,50	V	3	2.9	28.5	1.5x .8	60
30	17	V	1	56	56	.8x .8	60
TOTAL PAYLOADS			129				

CODE: M = MMS PAYLOAD, V = CANDIDATE FOR VERTICAL LAUNCH

* DATA FROM VOLUME III, TABLE 4-II, LES PAYLOAD MISSION MODEL

NOTE: (1) Diameter is from Mission Model Table 8-I. Maximum permissible diameter for direct mount in cargo bay is 4.47 m (14.67 ft.). Maximum diameter for support in the ASE is 4.0 m (13.12 ft.). The diameter of these payloads was reduced accordingly for this study.

TABLE 7-VIII

MODULAR BIPROPELLANT SCENARIO - B-2

PAYLOADS				LAUNCH MODE					
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	MODE-1 INTEG OMS	MODE-2 4-TANK	MODE-3 8-TANK	MODE-4 4-TANK VERT.	MODE-5 4-TANK VERT. +SSUS-A	MODE-6 4-TANK VERT. +SSUS-B
1	12		6	6					
2	13, 14, 15		10	10					
3	27		3		3				
4	43		1		1				
5	21, 32, 33, 34	M	10			10			
6	11	M	1		1				
7	2		4		4				
8	10	M	4		4				
9	23	M	3		3				
10	18, 25, 29-31, 35-39	M	18		18				
11	19, 42		3		3				
12	22, 28, 44, 46		19		19				
13	3		2			2			
14	45		12		12				
15	7, 8		3		3				
16	5, 24	V	4				4v		
17	4		3		3				
18	6, 40	V	4				4v		
19	16		1		1				
20	41	V	3				3v		
21	1		1		1				
22	9		1			1			
23	20	V	1				1v		
24	52	V	1				1v		
25	52		3					3 h	
26	48	V	1						1v
27	49	V	X						
28	53	V	2					2 h	
29	47, 51, 50	V	3			3h			
30	17	V	1				1v		
TOTAL			128	16	76	16	14	5	1

CODE M - MMS Payload, Candidate for PM-11
V - Candidate for Vertical Installation
h - horizontal Installation
v - vertical Installation
* - From Volume III, Table 4-II

TABLE 7-IX

MODULAR MONOPROPELLANT SCENARIO M-2

PAYLOADS				LAUNCH MODE					
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	MODE-1	MODE-2	MODE-3	MODE-4	MODE-5	MODE-6
				INTEG OMS	2-TANK	8-TANK	2-TANK VERT.	2-TANK VERT. +SSUS-D	2-TANK VERT. +SSUS-A
1	12		6	6					
2	13, 14, 15		10	10					
3	27		3		3				
4	43		1		1				
5	21, 32, 33, 34	M	10			10			
6	11	M	1			1			
7	2		4		4				
8	10	M	4		4				
9	23	M	3		3				
10	18, 25, 29-31, 35-39	M	18		18				
11	19, 42		3		3				
12	22, 28, 44, 46		19		19				
13	3		2			2			
14	45		12		12				
15	7, 8		3		3				
16	5, 24	V	4				4v		
17	4		3		3				
18	6, 40	V	4				4v		
19	16		1		1				
20	41	V	3				3v		
21	1		1		1				
22	9		1					1h	
23	20	V	1				1v		
24	52	V	1				1v		
25	52		3						3h,e
26	48	V	1					1v	
27	49	V	X						
28	53	V	2						2h,e
29	47, 51, 50	V	3					3v	
30	17	V	1				1v		
TOTAL			128	16	75	13	14	5	5

CODE M - MMS Payload, Candidate for PM-11
V - Candidate for Vertical Installation
h - horizontal Installation
v - vertical Installation
e - Elliptical Shuttle Orbit
* - From Volume III, Table 4-II

scheduled to be launched by Scout in 1981 (before WTR is operational) and the velocity change from a Shuttle launch of 56° is very high, approximately 4400 m/sec (14,436 ft/sec). Additionally, it was felt that the conceptual design of the LES should not be compromised to provide the velocity change capability for this payload as it falls outside the low energy regime as defined by Figure 4.2 of Volume III.

Payloads 52 (prior to 83) and 53 were used in the evaluation of new propulsion approaches even though they fall outside of the low energy regime since the adaptations did have the velocity change capability without compromise of the LES. The performance of the adaptations is shown in Volume III, Figure 4.39. The monopropellant adaptation had marginal performance for payloads 52 and 53 when launched from the standard orbit of 296 km (160 nm). The velocity change increment required for the monopropellant adaptation to capture payloads 52 and 53 was provided by flying the Orbiter to an elliptic orbit at 56° inclination with integral OMS after delivery of the shared flights payloads to 296 km (160 nm) and using the monopropellant adaptation make the plane change, altitude change and circularize the orbit.

The scenarios were selected on the basis of the most economical propulsion approach to launch each payload. For example, the modular bipropellant scenario shown in Table 7-VIII has 16 payloads being launched by integral OMS because the Orbiter integral OMS has the capability of direct delivery of these payloads and is the most economical choice. The same logic was used to select the 76 payloads for the modular 4-tank, 16 payloads for the modular 8-tank, etc. A detailed discussion of the bipropellant and monopropellant propulsion approach scenarios is presented in paragraphs 7.4.3.1 and 7.4.3.2.

Scenarios for existing/planned propulsion approaches that were selected are presented in Tables 7-X, 7-XI, 7-XII, 7-XIII, and 7-XIV. Typical of these existing/planned scenarios was E-1 shown in Table 7-X which used integral OMS, PM-II for those MMS payloads for which PM-II had the velocity change capability, two and four-tank TRS, Scout and SSUS-D to launch all 129 payloads of the mission model. Payload number 9 shown launched by SSUS-D has a highly elliptic orbit which is compatible with the SSUS-D single burn capability. Payload number 3 requires a 44.9° inclination and a circular orbit altitude of 556 km. In this scenario the Orbiter was launched to an

TABLE 7-X
EXISTING/PLANNED SCENARIO - E-1

PAYLOADS				LAUNCH MODE					
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	MODE-1	MODE-2	MODE-3	MODE-4	MODE-5	MODE-6
				INTEG OMS	MMS PM-II	TRS 2-TANK	TRS 4-TANK	SCOUT	SSUS-D
1	12		6	6					
2	13, 14, 15		10	10					
3	27		3			3			
4	43		1			1			
5	21, 32, 33, 34	M	10				10		
6	11	M	1				1		
7	2		4			4			
8	10	M	4		4				
9	23	M	3		3				
10	18, 25, 29, 31, 35-39	M	18		18				
11	19, 42		3			3			
12	22, 28, 44, 46		19			19			
13	3		2						2v,e
14	45		12			12			
15	7, 8		3			3			
16	5, 24	V	4			4 h			
17	4		3			3			
18	6, 40	V	4			4 h			
19	16		1			1			
20	41	V	3			3 h			
21	1		1			1			
22	9		1						1h,e
23	20	V	1			1 h			
24	52	V	1					1	
25	52		3					3	
26	48	V	1					1	
27	49	V	1					1	
28	53	V	2					2	
29	47, 51, 50	V	3					3	
30	17	V	1			1 h			
TOTAL			129	16	25	63	11	11	3

CODE M - MMS Payload, Candidate for PM-11
V - Candidate for Vertical Installation
h - horizontal Installation
v - vertical Installation
e - Elliptical Shuttle Orbit
* - From Volume III, Table 4-II

TABLE 7-XI

EXISTING/PLANNED SCENARIO E-2

PAYLOADS				LAUNCH MODE					
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	MODE-1	MODE-2	MODE-3	MODE-4	MODE-5	MODE-6
				INTEG OMS	TRS 2-TANK	TRS 4-TANK	SCOUT	SSUS-D	
1	12		6	6					
2	13, 14, 15		10	10					
3	27		3		3				
4	43		1		1				
5	21, 32, 33, 34	M	10			10			
6	11	M	1			1			
7	2		4		4				
8	10	M	4		4				
9	23	M	3		3				
10	18, 25, 29-31, 35-39	M	18		18				
11	19, 42		3		3				
12	22, 28, 44, 46		19		19				
13	3		2					2v,e	
14	45		12		12				
15	7, 8		3		3				
16	5, 24	V	4		4 h				
17	4		3		3				
18	6, 40	V	4		4 h				
19	16		1		1				
20	41	V	3		3h				
21	1		1		1 h				
22	9		1					1v,e	
23	20	V	1		1h				
24	52	V	1				1		
25	52		3				3		
26	48	V	1				1		
27	49	V	1				1		
28	53	V	2				2		
29	47, 51, 50	V	3				3		
30	17	V	1		1 h				
TOTAL			129	16	88	11	11	3	

CODE M - MMS Payload, Candidate for PM-11
V - Candidate for Vertical Installation
h - horizontal Installation
v - vertical Installation
e - Elliptical Shuttle Orbit
* - From Volume III, Table 4-II

TABLE 7-XII EXISTING/PLANNED SCENARIO E-3

PAYLOADS				LAUNCH MODE					
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	MODE-1	MODE-2	MODE-3	MODE-4	MODE-5	MODE-6
				INTEG OMS	OMS 1 KIT	OMS 1-KIT +SSUSD	INTEG OMS +SSUSD	SCOUT	
1	12		6	6					
2	13,14,15		10	10					
3	27		3	3					
4	43		1			1e,i			
5	21,32,33,34	M	10			10e,i			
6	11	M	1		1				
7	2		4	4					
8	10	M	4	4					
9	23	M	3		3				
10	18,25,29-31, 35-39	M	16		14	4e			
11	19,42		3		1	2 e,i			
12	22,28,44,46		19			19e			
13	3		2		2				
14	45		12		6	6e			
15	7,8		3		3				
16	5,24	V	4			4v,e,i			
17	4		3			3e,i			
18	6,40	V	4	2h	2h				
19	16		1		1				
20	41	V	3	3h					
21	1		1	1					
22	9		1				1e		
23	20	V	1	1h					
24	52	V	1					1	
25	52		3					3	
26	48	V	1					1	
27	49	V	1					1	
28	53	V	2					2	
29	47,51,50	V	3					3	
30	17	V	1		1h				
	TOTAL		129	34	34	49	1	11	

CODE M - MMS Payload, Candidate for PM-11.

V - Candidate for Vertical Installation..

h - horizontal Installation

v - vertical Installation

e - Elliptical Shuttle Orbit

i - Shuttle Launch at Payload Inclination

* - From Volume III, Table 4-II

TABLE 7-XIII

EXISTING/PLANNED SCENARIO E-4

PAYLOADS				LAUNCH MODE					
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	MODE-1 INTEG OMS	MODE-2 OMS 1 KIT	MODE-3 TRS 2 TANK	MODE-4 TRS 4 TANK	MODE-5 SSUS-D	MODE-6 SCOUT ELV
1	12		6	6					
2	13, 14, 15		10	10					
3	27		3	3					
4	43		1			1			
5	21, 32, 33, 34	M	10				10		
6	11	M	1		1				
7	2		4	4					
8	10	M	4	4					
9	23	M	3		3				
10	18, 25, 29-31, 35-39	M	18		14	4			
11	19, 42		3		1	2			
12	22, 28, 44, 46		19			19			
13	3		2		2				
14	45		12		6	6			
15	7, 8		3		3				
16	5, 24	V	4			4 _h			
17	4		3			3			
18	6, 40	V	4	2	2 _h				
19	16		1		1				
20	41	V	3	3 _h					
21	1		1	1					
22	9		1					1 _e	
23	20	V	1	1 _h					
24	52	V	1						1
25	52		3						3
26	48	V	1						1
27	49	V	1						1
28	53	V	2						2
29	47, 51, 50	V	3						3
30	17	V	1		1				
TOTAL			129	34	34	39	10	1	11

CODE M - MMS Payload, Candidate for PM-11
V - Candidate for Vertical Installation
h - horizontal Installation
v - vertical Installation
e - Elliptical Shuttle Orbit
* - From Volume III, Table 4-II

TABLE 7-XIV EXISTING/PLANNED SCENARIO E-5

PAYLOADS				LAUNCH MODE							
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	M-1 INT OMS	M-2 OMS 1 KIT	M-3 OMS 1 KIT +SSUSD	M-4 PM II	M-5 PM II OMS	M-6 PM-II +1 KIT	M-7 SCOUT	M-8 INT OMS +SSUSD
1	12		6	6							
2	13, 14, 15		10	10							
3	27		3	3							
4	43		1			1e,i			10e,i		
5	21,32,33,34	M	10								
6	11	M	1					1			
7	2		4	4							
8	10	M	4				4				
9	23	M	3				3				
10	18,25,29-31. 35-39	M	18				18				
11	19,42		3		1	2e,i					
12	22,28,44,46		19			19e					
13	3		2		2						
14	45		12		6	6e					
15	7,8		3		3	4h,e,i					
16	5,24	V	4			4h,e,i					
17	4		3			3e,i					
18	6,40	V	4	2	2h						
19	16		1								
20	41	V	3	3h							
21	1		1	1l							
22	9		1								1e
23	20	V	1	1h							
24	52	V	1							1	
25	52		3							3	
26	48	V	1							1	
27	49	V	1							1	
28	53	V	2							2	
29	47,51,50	V	3							3	
30	17	V	1		1h						
TOTAL			129	30	16	35	25	1	10	11	1

CODE M - MMS Payload, Candidate for PM-11.
 V - Candidate for Vertical Installation.
 h - horizontal Installation
 v - vertical Installation
 e - Elliptical Shuttle Orbit
 i - Shuttle Launch at Payload Inclination
 * - From Volume III, Table 4-II

altitude of 556 km (300 nm) in an elliptical orbit at 56° inclination. The SSUS-D was used to make the plane change of 11.1° and circularize the payload orbit. Energy management of the SSUS-D was achieved by selective latitude firing of the SSUS-D. A more detailed discussion of the existing/planned propulsion approach scenarios can be found in paragraph 7.4.4.1. Other scenarios that were selected are presented in Tables 7-XV, 7-XVI, 7-XVII, and 7-XVIII. For these scenarios a new propulsion approach was used in combination with existing/planned approaches. Typical of this approach is scenario C-2 presented in Table 7-XVI which used integral OMS, the modular bipropellant and Scout to launch all 129 payloads. A more detailed discussion of these scenarios can be found in paragraph 7.4.4.2.

7.4.3 Selection of Candidate New Propulsion Approach

The costs were derived for each scenario by summation of the production, operations and development costs. A typical example of the cost buildup for scenario C-2 is presented in Table 7-XIX. The number of payloads launched by each modular version of the bipropellant approach, integral OMS and Scout is shown. The costs associated with the number of payloads launched by each propulsion approach including the DDT&E cost of the modular bipropellant are summed to give the total cost to launch all 129 payloads. The payload charge was removed to show the scenario cost without the payload charge. The payload charge varied with each scenario due to vertical and horizontal installation differences and length and weight installation differences between the scenarios. All scenarios examined can be found in Volume V, Appendix C. A summary of the scenario costs is presented in Table 7-XX. Figure 7.5 is a bar chart comparing the costs of candidate new propulsion approaches. Total cost (Table 7-XX) was used as a basis for cost/benefit analysis.

7.4.3.1 Modular Bipropellant Benefits Analysis - Scenario B-1 of

Figure 7.5 consisted of the modular 4 and 8 tank version with all payloads installed horizontal except the SSUS-D adaptation.

Scenario B-2 was designed to explore the cost benefits of adding a vertical launch capability to B-1. The cost benefit relative to Scenario B-1 was \$6.7M as presented in Table 7-XX.

Scenario B-3 was designed to show the effect of providing a vertical installation with a very high velocity change capability. A negative

TABLE 7-XV
COMBINATION SCENARIO C-1

PAYLOADS				LAUNCH MODE					
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	MODE-1	MODE-2	MODE-3	MODE-4	MODE-5	MODE-6
				INTEG OMS	4 TANK BIPROP	8 TANK BIPROP	SCOUT		
1	12		6	6					
2	13, 14, 15		10	10					
3	27		3		3				
4	43		1		1				
5	21, 32, 33, 34	M	10			10			
6	11	M	1		1				
7	2		4		4				
8	10	M	4		4				
9	23	M	3		3				
10	18, 25, 29-31, 35-39	M	18		18				
11	19, 42		3		3				
12	22, 28, 44, 46		19		19				
13	3		2			2			
14	45		12		12				
15	7, 8		3		3				
16	5, 24	V	4		4h				
17	4		3		3				
18	6, 40	V	4		4h				
19	16		1		1				
20	41	V	3		3h				
21	1		1		1				
22	9		1			1			
23	20	V	1		1h				
24	52	V	1		1h				
25	52		3				3		
26	48	V	1				1		
27	49	V	1				1		
28	53	V	2				2		
29	47, 51, 50	V	3				3		
30	17	V	1		1h				
TOTAL			129	16	90	13	10		

CODE M - MMS Payload, Candidate for PM-11
V - Candidate for Vertical Installation
h - horizontal Installation
v - vertical Installation
* - From Volume III, Table 4-II

TABLE 7-XVI
COMBINATION NEW AND EXISTING/PLANNED SCENARIO C-2

PAYLOADS				LAUNCH MODE					
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	MODE-1	MODE-2	MODE-3	MODE-4	MODE-5	MODE-6
				INTEG OMS	4 TANK BIPROP	8 TANK BIPROP	4 TANK BIPROP VERT.	SCOUT	
1	12		6	6					
2	13, 14, 15		10	10					
3	27		3		3				
4	43		1		1				
5	21, 32, 33, 34	M	10			10			
6	11	M	1		1				
7	2		4		4				
8	10	M	4		4				
9	23	M	3		3				
10	18, 25, 29-31, 35-39	M	18		18				
11	19, 42		3		3				
12	22, 28, 44, 46		19		19				
13	3		2			2			
14	45		12		12				
15	7, 8		3		3				
16	5, 24	V	4				4v		
17	4		3		3				
18	6, 40	V	4				4v		
19	16		1		1				
20	41	V	3				3v		
21	1		1		1				
22	9		1			1			
23	20	V	1				1v		
24	52	V	1				1v		
25	52		3					3	
26	48	V	1					1	
27	49	V	1					1	
28	53	V	2					2	
29	47, 51, 50	V	3					3	
30	17	V	1				1v		
TOTAL			129	16	76	13	14	10	

CODE M - MMS Payload, Candidate for FM-11
V - Candidate for Vertical Installation
h - horizontal Installation
v - vertical Installation
* - From Volume III, Table 4-II

TABLE 7-XVII
COMBINATION SCENARIO C-3

PAYLOADS				LAUNCH MODE					
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	MODE-1	MODE-2	MODE-3	MODE-4	MODE-5	MODE-6
				INTEG OMS	4 TANK BIPROP	4 TANK BIPROP	4 TANK BP & SSUS-D	SCOUT	
1	12		6	6					
2	13, 14, 15		10	10					
3	27		3		3				
4	43		1		1				
5	21, 32, 33, 34	M	10				10h		
6	11	M	1		1				
7	2		4		4				
8	10	M	4		4				
9	23	M	3		3				
10	18, 25, 29-31, 35-39	M	18		18				
11	19, 42		3		3				
12	22, 28, 44, 46		19		19				
13	3		2				2h		
14	45		12		12				
15	7, 8		3		3				
16	5, 24	V	4			4h			
17	4		3		3				
18	6, 40	V	4			4h			
19	16		1		1				
20	41	V	3			3h			
21	1		1		1				
22	9		1				1h		
23	20	V	1			1h			
24	52	V	1			1h			
25	52		3					3	
26	48	V	1					1	
27	49	V	1					1	
28	53	V	2					2	
29	47, 51, 50	V	3					3	
30	17	V	1			1h			
TOTAL			129	16	76	14	13	10	

CODE M - MMS Payload, Candidate for PM-11
V - Candidate for Vertical Installation

h - Horizontal Installation

v - Vertical Installation

* - From Volume III, Table 4-II

TABLE 7-XVIII

COMBINATION SCENARIO C-4

PAYLOADS				LAUNCH MODE					
PAYLOAD GROUP NO.	PAYLOAD IDENTIFICATION NUMBERS *	CODE	NUMBER OF PAYLOADS	MODE-1	MODE-2	MODE-3	MODE-4	MODE-5	MODE-6
				INTEG. OMS	PM II	4 TANK BIPROP	8 TANK BIPROP	SCOUT	
1	12		6	6					
2	13, 14, 15		10	10					
3	27		3			3			
4	43		1			1			
5	21, 32, 33, 34	M	10				10		
6	11	M	1			1			
7	2		4			4			
8	10	M	4		4				
9	23	M	3		3				
10	18, 25, 29-31, 35-39	M	18		18				
11	19, 42		3			3			
12	22, 28, 44, 46		19			19			
13	3		2				2		
14	45		12			12			
15	7, 8		3			3			
16	5, 24	V	4			4h			
17	4		3			3			
18	6, 40	V	4			4h			
19	16		1			1			
20	41	V	3			3h			
21	1		1			1			
22	9		1				1		
23	20	V	1			1h			
24	52	V	1			1h			
25	52		3					3	
26	48	V	1					1	
27	49	V	1					1	
28	53	V	2					2	
29	47, 51, 50	V	3					3	
30	17	V	1			1h			
TOTAL			129	16	25	65	13	10	

CODE M - MMS Payload, Candidate for PM-11
V - Candidate for Vertical Installation
h - horizontal Installation
v - vertical Installation
* - From Volume III, Table 4-II

TABLE 7-XIX
COST SUMMARY

		SCENARIO COSTS \$M				SCENARIO NO. C-2				
WBS NO.	COST ITEM	NUMBER OF PAYLOADS	16	76	13	14	10			
		Propulsion Approach	INTEG OMS	MODULAR 4-TANK HORIZ. BIPROP*	MODULAR 8-TANK HORIZ. BIPROP	MODULAR 4-TANK VERTICAL BIPROP*	SCOUT			NON RECUR COST
1-D	DDT&E									26.1
1-P	PRODUCTION		0	133.5	27.8	24.8	0			186.1
1-0	OPERATIONS - TOTAL		283.7	698.7	166.0	63.9	57.6			1,269.9
	(Supporting Costs)		0	(40.2)	(6.9)	(7.4)	(14.4)			*(68.9)
	(Shuttle Charge Total)		(283.7)	(658.5)	(159.1)	(56.5)	---			(1,157.8)
	Payload Charge		280.5	532.4	131.3	18.1	---			962.3
	Stage Charge		---	126.1	27.8	38.4	---			192.3
	Other Charges		3.2	---	---	---	---			3.2
	(Scout Launch Charge)		---	---	---	---	(43.2)			(43.2)
	TOTAL COST		283.7	832.2	193.8	88.7	57.6			26.1
Total Without Payload Charge										519.8

*Supporting costs include:

Annual Operations Cost

Unit Operations cost

(23.6 + 4.0 + 4.3)

Total

36.9

32.0

68.9

* 415 Kg Offload, Refer to paragraph 4.7.1 of Volume III

TABLE 7-XX
SUMMARY OF SCENARIO COSTS - \$M

SCENARIO																		
	BIPROPELLANT					MONOPROPELLANT				EXISTING/PLANNED					COMBINATION			
	E-1	B-2	B-3	B-4	B-5	M-1	M-2	M-3	M-4	E-1	E-2	E-3	E-4	E-5	C-1	C-2	C-3	C-4
DDT&E	28.8	31.6	44.4	26.5	28.1	27.0	27.7	23.3	24.2	0	0	0	0	0	23.3	26.1	23.4	23.3
Production	225.5	225.7	227.2	238.5	258.7	191.0	191.0	216.1	216.1	94.5	83.5	121.3	51.5	122.5	185.9	186.1	212.9	186.4
Operations (Total)	1281.7	1272.0	1260.8	1331.3	1321.7	1313.0	1302.5	1360.9	1350.4	1508.7	1534.7	2164.1	1700.0	1990.0	1279.6	1269.9	1318.2	1318.6
Supporting Costs	57.4	57.4	57.4	57.4	57.4	57.5	57.5	57.4	57.4	64.9	76.3	54.4	47.5	75.7	69.0	68.9	68.9	78.7
Payload Charge	985.2	982.5	976.2	988.4	986.8	902.5	900.6	975.8	973.9	951.3	882.5	633.0	893.6	703.6	963.9	962.3	969.2	963.9
Stage Charge	235.9	228.9	224.0	282.3	274.3	348.8	340.2	323.5	314.9	421.7	525.0	1356.3	677.7	1109.5	200.3	192.3	235.7	229.5
Other Charges	3.2	3.2	3.2	3.2	3.2	4.2	4.2	4.2	4.2	3.8	3.8	73.4	34.2	54.2	3.2	3.2	3.2	3.2
Scout Launch Charge	0	0	0	0	0	0	0	0	0	47.0	47.0	47.0	47.0	47.0	43.2	43.2	43.2	43.2
Total Cost	1536.0	1529.3	1532.4	1616.3	1608.5	1531.0	1521.2	1600.3	1590.7	1603.2	1618.2	2285.4	1751.5	2112.5	1488.8	1482.1	1554.5	1508.5
Total W/O Payload	550.8	546.6	556.2	627.9	621.7	620.5	620.6	624.5	616.8	651.9	735.7	1652.4	657.9	1408.9	524.9	519.6	555.3	544.6

NOTE: 1) SEE VOLUME V, APPENDIX C FOR DEFINITIONS AND COSTS OF ALL SCENARIOS

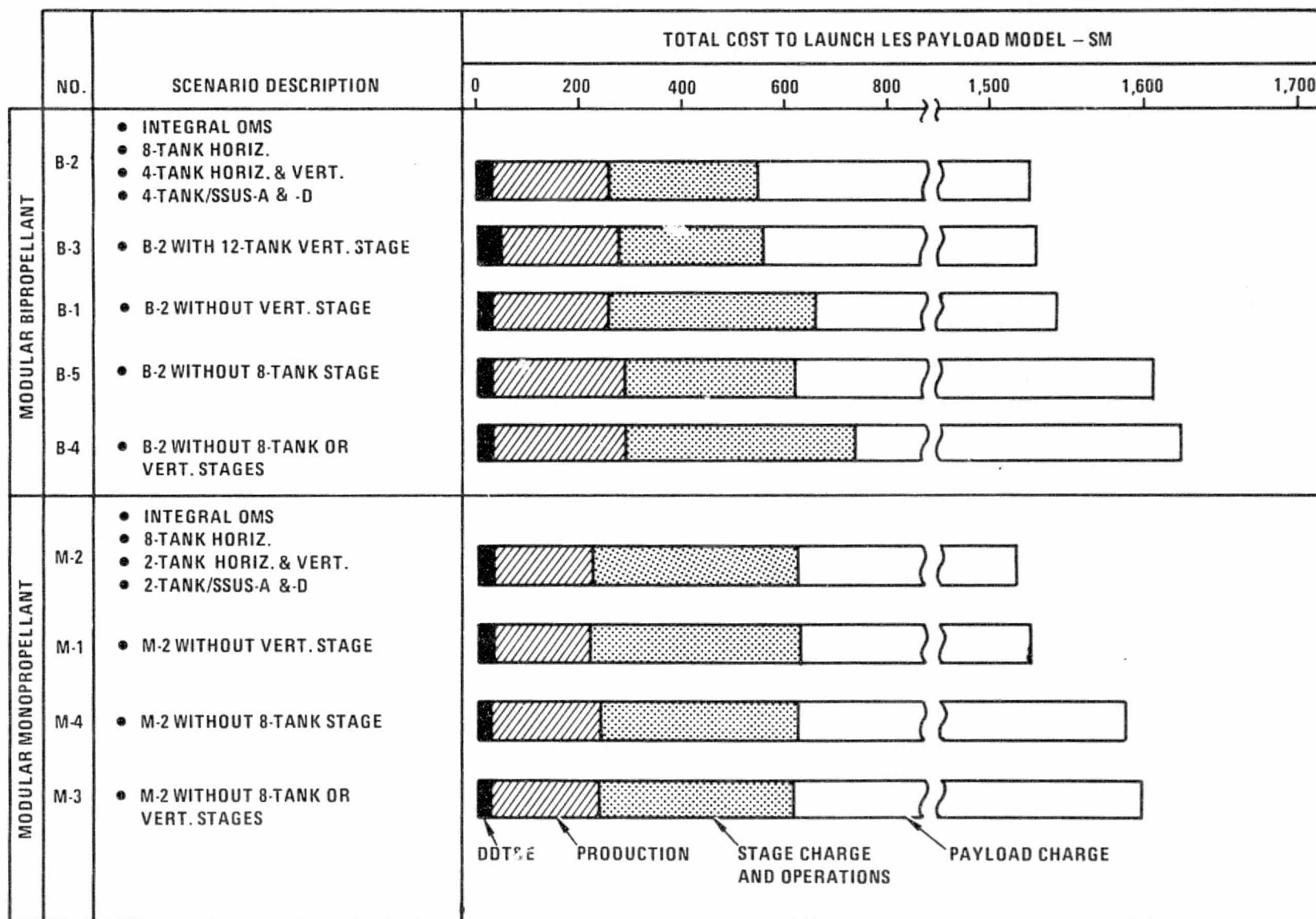


FIGURE 7.5 SCENARIO COST COMPARISON OF MODULAR BI-PROPELLANT AND MODULAR MONO-PROPELLANT PROPULSION APPROACHES

cost benefit of \$3.1M relative to B-2 resulted from the inclusion of this 12-tank vertical version in the scenario.

Scenario B-4 was designed to test the possibility of using a 4-tank version only and combining it with SSUS-A or SSUS-D to capture the regime. A negative cost benefit of \$87.0M resulted relative to B-2 cost.

Scenario B-5 was designed to add a vertical launch capability to B-4. A negative cost benefit of \$79.2M resulted relative to B-2.

The costs for scenarios B-1, B-2 and B-3 were essentially equal; therefore, other benefits were explored in order to make a selection. The costs for these scenarios are summarized in Table 7-XXI.

Scenario B-1 is the least complex and is less costly to develop; however, its cost is \$6.7M more than B-2 and it does not provide a vertical launch capability. A vertical capability will attract more payloads due to lower user cost with a resulting increase in Shuttle utilization due to shorter cargo length. B-1 was eliminated from further consideration on these bases.

Scenario B-3 had the highest complexity and the highest development cost of the three. The one advantage was its capability to handle very high AV payloads, up to 3300 meters/sec (10827 ft/sec), from the vertical installed position. The three payloads in this AV regime of the mission model can be handled by Scout for approximately \$6.5M each. The comparable recurring cost to use the Shuttle for these payloads, using the 12-tank vertical installation would be about \$4.4M each. Cost was the prime motivation behind the generation of the 12-tank concept; however, since there are no payloads in this AV regime after 1982, there was no justification to add extra development costs of \$12.8M to provide this capability. However, should future payloads develop in this AV regime the 8-tank configuration could handle them for a recurring cost of approximately \$8.5M each. Scenario B-3 was eliminated from further consideration.

Scenario B-2 was selected as the most attractive modular bipropellant approach.

7.4.3.2 Modular Monopropellant Scenario Benefits Analysis - Scenario M-1 of Figure 7.5 consisted of modular 2 and 8-tank configurations installed horizontally except for the SSUS-D "adaptation".

TABLE 7-XXI BIPROPELLANT
SCENARIO AND COST SUMMARY

<u>Scenario</u>	<u>Scenario Description and Costs</u>	
B-1	Integral OMS	- 16 payloads
	4 Tank - H	- 90 payloads
	8 Tank - H	- 16 payloads
	4 Tank H/SSUS-D	- 1 payload
	4 Tank F/SSUS-A	- 5 payloads
	TOTAL	128 payloads
	Scenario Cost = \$1536.0M	
B-2	<u>Development cost = \$28.8M</u>	
	Integral OMS	- 16 payloads
	4 Tank - H	- 76 payloads
	4 Tank - V	- 14 payloads
	8 Tank - H	- 16 payloads
	4 Tank V/SSUS-D	- 1 payload
	4 Tank V/SSUS-A	- 5 payloads
	TOTAL	128 payloads
B-3	Scenario cost = \$1529.3M	
	<u>Development cost = \$31.6M</u>	
	Integral OMS	- 16 payloads
	4 Tank - H	- 76 payloads
	8 Tank - H	- 18 payloads
	12 Tank - V	- 3 payloads
	4 Tank - V	- 14 payloads
	4 Tank H/SSUS-D	- 1 payload
	4 Tank H/SSUS-A	- 5 payloads
	TOTAL	128 payloads
	Scenario cost = \$1532.4M	
	Development cost = \$44.4M	

Scenario M-2 explored the benefits of adding a vertical launch capability to the monopropellant approach. The resulting cost benefit relative to Scenario M-1 was \$9.8M as presented in Table 7-XX.

Scenario M-3 was designed to evaluate the possibility of using a 2-tank version only and combining it with SSUS-A or SSUS-D to capture the regime. The resulting benefit relative to M-2 was a negative \$79.1M.

Scenario M-4 explored the cost benefit of adding a vertical launch capability to M-3. The resulting benefit relative to M-2 was a negative \$69.5M.

Scenarios M-1 and M-2 were essentially equal in cost benefits; consequently other benefits were explored in order to make a selection. M-1 and M-2 scenarios are summarized in Table 7-XXII. Scenario M-2, the Modular monopropellant approach, was the least costly approach. Its development cost was up by \$.7M. However, it provided a vertical launch capability resulting in a net savings of \$9.8M. This capability will attract more payloads due to lower user cost with a resulting increase in Shuttle utilization due to the shorter cargo length.

Scenario M-2 was selected as the most attractive modular monopropellant.

7.4.3.3 Selection of the Candidate New Propulsion Approach - A summary of the selected bipropellant and monopropellant scenario costs is shown in Table 7-XXIII. The selection of the best new propulsion approach was accomplished by cost/benefits and other benefit analysis as follows.

Cost Benefits - The M-2 scenario costs are \$8.1M less than B-2 and requires \$3.9M less to develop. The operation costs shown in Table 7-XX, including the Shuttle charge, are \$30.5M more than B-2 due to the shorter length of the bipropellant approach. The unit cost of M-2 is lower by \$34.7M than B-2 partially due to a separate RCS in the bipropellant concept. The monopropellant has reaction control built into the primary propulsion. This same approach was a potential for bipropellant with about a 5% reduction in maximum velocity change capability and a decreased production cost of approximately \$10M for the scenario. With this change the development cost of the bipropellant would also reduce by about \$1M. With the 5% reduction in maximum ΔV the bipropellant still met the mission requirements at the higher payload weights and out-performed the monopropellant by 30% at low payload

TABLE 7-XXII

MODULAR MONOPROPELLANT SCENARIO AND COST SUMMARY

<u>Scenario</u>	<u>Scenario Description and Cost</u>	
M-1	Integral OMS	- 16 payloads
	2 Tank - H	- 89 payloads
	8 Tank - H	- 13 payloads
	2 Tank V/SSUS-D	- 5 payloads
	2 Tank V/SSUS-A	- 5 payloads
	TOTAL	-128 payloads
	Scenario cost = \$1531.0	
M-2	<u>Development cost = \$27.0M</u>	
	Integral OMS	- 16 payloads
	2 Tank - H	- 75 payloads
	2 Tank - V	- 14 payloads
	8 Tank - H	- 13 payloads
	2 Tank V/SSUS-D	- 5 payloads
	2 Tank V/SSUS-A	- 5 payloads
	TOTAL	-128 payloads
	Scenario cost = \$1521.2M	
	Development cost = \$27.7M	

TABLE 7-XXIII

SUMMARY OF LOWEST COST BIROPELLANT AND MONOPELLANT SCENARIO COSTS

<u>Scenario</u>	<u>Scenario Description and Cost</u>	
Bipropellant Scenario B-2	Integral OMS	- 16 payloads
	4 Tank - H	- 76 payloads
	4 Tank - V	- 14 payloads
	8 Tank - H	- 16 payloads
	4 Tank V/SSUS-D	- 1 payload
	4 Tank V/SSUS-A	- 5 payloads
	TOTAL	128 payloads
	Scenario Cost = \$1529.3M	
	<u>Development cost = \$31.6M</u>	
Monopropellant Scenario M-2	Integral OMS	- 16 payloads
	2 Tank - H	- 75 payloads
	2 Tank - V	- 14 payloads
	8 Tank - H	- 13 payloads
	2 Tank V/SSUS-D	- 5 payloads
	2 Tank V/SSUS-A	- 5 payloads
	TOTAL	128 payloads
	Scenario Cost = \$1521.2M	
	<u>Development cost = \$27.7M</u>	

weights. The scenario cost comparison with these changes incorporated was as follows:

Scenario B-2 Cost = \$1519.3M
Development Cost = \$30.6M - Included in Scenario Cost

Scenario M-2 Cost = \$1521.2M
Development Cost = \$27.7M - Included in Scenario Cost

Other Benefits

(a) Shuttle Utilization - The modular bipropellant was shorter and lighter than the modular monopropellant due to the higher specific impulse and higher propellant bulk density and a resulting smaller fuel volume. This would allow more efficient utilization of Shuttle cargo volume.

(b) Stage and Payload Retrieval and Re-Use Potential - The modular bipropellant has the higher performance and provides stage recovery potential from greater distances after delivery of heavier payloads.

(c) Development Risk - This was considered to be equal since bipropellant hardware is being developed for the Shuttle.

(d) Accuracy - This was considered equal since the guidance system was common to both approaches.

(e) Mission Capture - Both scenarios captures 99% of the model payloads not being delivered direct by the Shuttle. The bipropellant without SSUS "adaptations" captured 95% of the mission model as compared to 90% for the monopropellant.

(f) Energy Regime Capture - Both scenarios captured 100% of the regime out to a velocity increment of 3657 m/sec (12000 ft/sec) at a stage weight of 600 kg which is considered to be the energy regime after 1983 with WTR operational. (Refer to Volume III, Figure 4.2) The modular bipropellant without "adaptations" to the SSUS captures 85% of the regime as compared to 78% for the monopropellant.

(g) Shuttle Operations - The two approaches were considered essentially equal from a hazard implication standpoint.

From the cost/benefit analysis the modular bipropellant and the modular monopropellant were essentially equal. Other benefits favored the bipropellant.

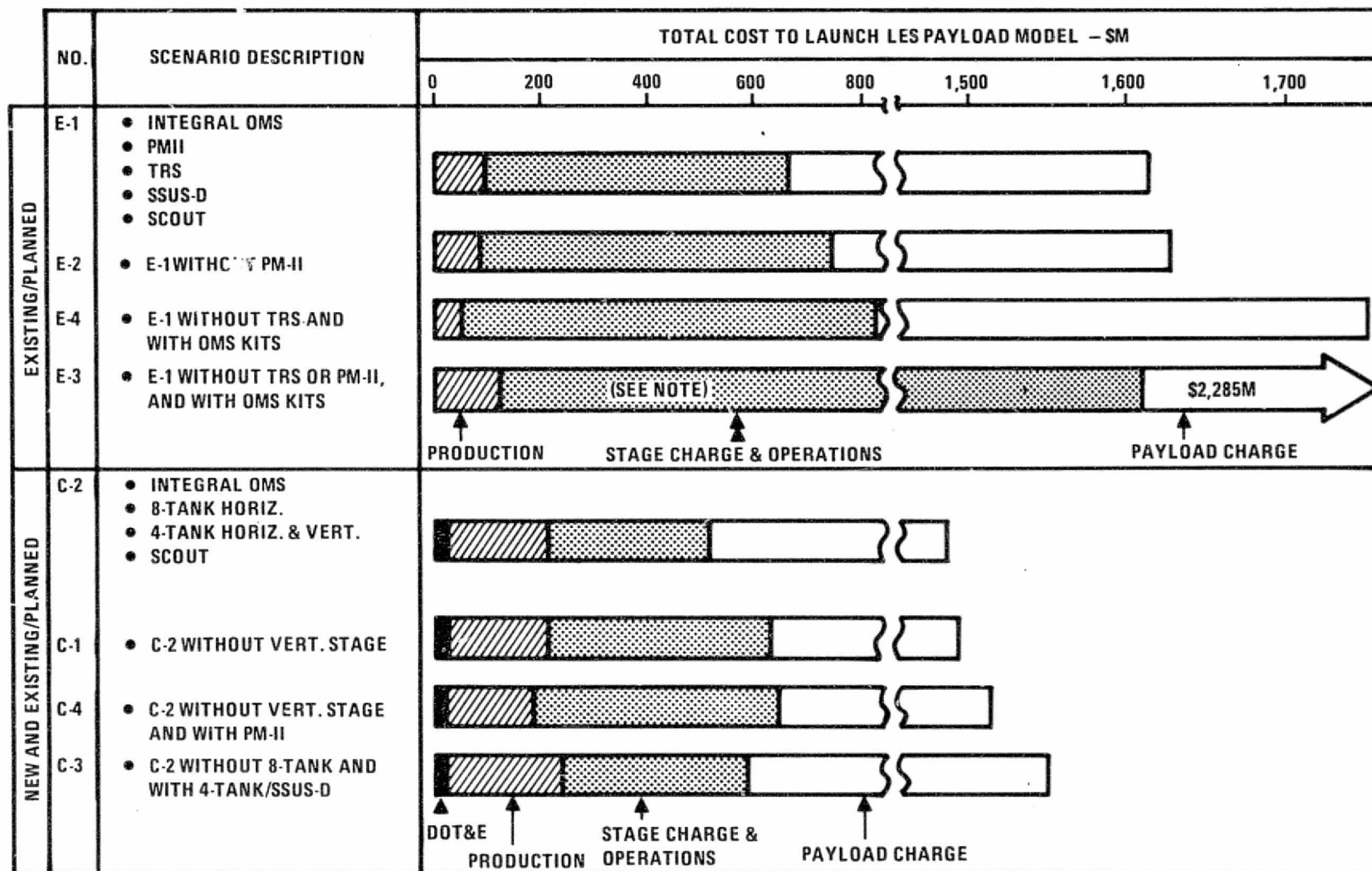
The modular bipropellant had the most potential for growth and mission capture; therefore, it was selected without the RCS modification for comparison with existing/planned approaches. The costs were essentially equal without the modification therefore the RCS approach was considered to be an issue to be resolved upon the initiation of detail design.

7.4.4 Selection of the Lowest Cost Existing/Planned and New/Combination Approaches

Costs comparison of existing/planned and new/combination scenarios is shown in Figure 7.6. The cost data for these scenarios is summarized in Table 7-XX. The data was analyzed and the lowest cost existing/planned approach and the lower cost new/combination with existing/planned approach was selected.

7.4.4.1 Selection of the Lowest Cost Existing/Planned Approach ~ The scenarios for the existing/planned approaches are summarized in Table 7-X through 7-XIV. The costs are summarized in Table 7-XX. Table 7-XXIV presents a cost comparison for the Scout ELV and the STS to deliver the eleven Scout class payloads. The costs to deliver 10 of these payloads with Scout or with SSUS-A and SSUS-D on the Shuttle show that Scout will save about \$20M in 1977 dollars prior to 1983. After WTR operation in 1983 Scout remains the most economical approach to launch the remaining Transit. Scout annual program maintenance costs were spread across the launches scheduled for each year. San Marco and AMPTE missions were considered launched from the San Marco launch site. The AMPTE-A and B missions require a five-stage Scout. STS launch costs using SSUS-A or -D included (1) shared-flight charge (U. S. Govt. or participating Foreign Govt.) for the payload and stage and non-standard orbit change (elliptical), (2) SSUS-A or -D baseline hardware, analyses and services for each launch, and (3) SSUS-A and -D additional mission specific analysis for each different mission, plus services for each launch. Based on the indicated saving, Scout was used in all existing/planned scenarios. See Volume V, Appendix C for examples of the Scout and STS launch cost comparison. If the shuttle charge for DOD Payloads is considered (12.2 \$M X escalation to 1977 \$) Scout still saves about \$18M.

Scenario E-1 consisted primarily of the 2 and 4-tank TRS, PM-II and Scout. E-1 was designed to test the cost benefits of using the PM-II for those MMS payloads that it could capture as compared to scenario E-2 in which the same 25 payloads were launched by the 2-tank TRS. A cost benefit of \$15.0M was indicated when PM-II was used.



NOTE: SHUTTLE TO CIRCULAR OR ELLIPTICAL ORBITS AT REQUIRED INCLINATIONS ABOVE 28.5°

FIGURE 7.6 SCENARIO COST COMPARISON OF EXISTING/PLANNED AND NEW PROPULSION APPROACHES

TABLE 7-XXIV SCOUT ELV VERSUS STS LAUNCH COSTS
FOR SCOUT CLASS PAYLOADS

(MILLIONS OF 1977 DOLLARS)

• PRIOR TO WTR OPERATION

PAYLOAD NO.	MISSION NAME	SCHEDULE			SCOUT LAUNCH COST (\$M)	STS LAUNCH COST (\$M)	STS UPPER STAGE
		80	81	82			
47	San Marco D _m	1			5.42	7.54	SSUS-D
48	San Marco D ₁	1			5.42	7.54	SSUS-D
49	Solar Mesosphere Exp.		1		5.42	12.01	SSUS-A
50	AMPTE A		1		6.92	7.54	SSUS-D
51	AMPTE B			1	6.52	7.54	SSUS-D
52	Transit (DoD)	1	1	1	15.86	21.12	SSUS-D
53	Canadian Scientific			2	10.04	14.33	SSUS-D
TOTAL		3	3	4	55.60	77.62	

↓ SCOUT SAVES \$22.02M

• AFTER WTR OPERATION

COST TO LAUNCH ONE TRANSIT IN 1983:

Scout	\$8.63 (Note 1)
STS-SSUS-D	9.19
STS-LHS	6.13

NOTE: (1) ONLY ONE SCOUT CLASS PAYLOAD LAUNCHED IN '83, COST INCLUDES \$4.81 M OF ANNUAL PROGRAM MAINTENANCE COST.

Scenario E-4 was derived to show the cost impact of using an OMS kit to capture all payloads within its capability. A negative benefit of \$148.3M resulted relative to E-1.

Scenarios E-3 and E-5 were designed for STS cost evaluation without the TRS. The Shuttle was allowed to launch to the payload inclination and where necessary elliptical Shuttle orbits were used in combination with SSUS-D to inject payloads into their destination orbits. Scenario E-3 required 50 non-standard orbits (30 elliptical) and E-5 required 46 non-standard orbits (26 elliptical). Scenario E-3 without TRS or PM-II had a total cost of \$2285.4M and scenario E-5 without TRS but with PM-II had a total cost of \$2112.5M. This compares to the \$1603.2M derived for scenario E-1.

The lowest cost scenario is E-1 which consists primarily of TRS, PM-II and Scout. This scenario was selected as the lowest cost approach for existing/planned systems.

7.4.4.2 Selection of the Lowest Cost New/Combination with Existing/

Planned Approach - The scenarios for the combination new and existing/planned approaches are summarized in Table 7-XV through 7-XVII. The costs are summarized in Table 7-XX. Scout was the most economical choice to launch 10 of the 11 payloads in these scenarios. The STS cost to launch the Transit payload in 1983, using LES as the upper stage, was \$6.13M compared to \$8.63M for Scout. The increased cost for the Scout launch as reflected in Table 7-XXIV was due to the amortization of all the annual Scout program maintenance cost of \$4.81M over the one payload for Scout scheduled for 1983. The STS with LES as the upper stage was used to launch the 1983 Transit in all new/combination scenarios.

Scenario C-1 consisted primarily of the 8-tank modular bipropellant and Scout. All payload installations were horizontal. It was designed to test the cost benefits of this approach against the provision for vertical installation in Scenario C-2. A cost benefit relative to C-1 of \$6.7M was shown.

Scenario C-3 was the same as C-2 except that only the horizontal and vertical 4-tank bipropellant were used. Those payloads normally captured by the 8-tank version were launched by the SSUS-D "adaptation". A negative cost benefit of \$72.4M resulted relative to C-2 cost.

Scenario C-4 was the same as C-1 except for the inclusion of PM-II for 25 payloads that it could capture. C-4 was designed to test the cost benefits of the PM-II in the new/combination scenarios. Negative cost benefits due to the PM-II of \$26.4M were indicated relative to C-2.

Scenario C-2 was selected as the lowest cost new combined with existing/planned approach. It consisted of the modular 4 and 8 tank bipropellant with vertical installation capability used in conjunction with Scout and integral OMS.

7.4.5 Approach Selection

In paragraph 7.4.4.1 the lowest cost existing/planned approach was selected consisting of the STS with integral OMS, TRS, PM-II and Scout. The cost of this scenario was \$1603.2M. In paragraph 7.4.4.2 the lowest cost new/combination with existing planned approach was selected consisting of integral OMS, a new low energy stage, and Scout. The cost for this scenario was \$1482.1M. The cost of these two cost effective scenarios are compared to the cost of the STS without a low energy stage using integral OMS, OMS kits, SSUS-D, Scout and non-standard orbits in Figure 7.7. Cost savings of \$682M and \$803M are indicated for the use of the TRS/PM-II and a new LES, respectively. In assessing the economic merits of these two most cost effective scenarios, it is necessary to establish the effect of timing as well as the magnitude of the costs. The life cycle cost streams of (1) the most cost effective scenario made up of existing/planned systems (E-1) and of (2) the similar scenario containing the new LES system (C-2) are shown as cumulative costs to deliver the LES payload model in Figure 7.8. The additional Shuttle charge for the payloads of the model, common to both scenarios, of 950 million 1977 dollars (Refer to Table 7-XX), is noted in the figure. The payload Shuttle charge for scenarios E-1 and E-2 are essentially the same, differing only due to differences in vertical and horizontal installations and differences in weight versus length critical installations. The payload Shuttle charges are:

For Scenario C-2	\$962,354,000
For Scenario E-1	\$951,224,000
Difference	\$ 11,130,000

In the comparison of these two scenarios without the payload charge the lesser E-1 payload charge (the amount considered to be common to both approaches)

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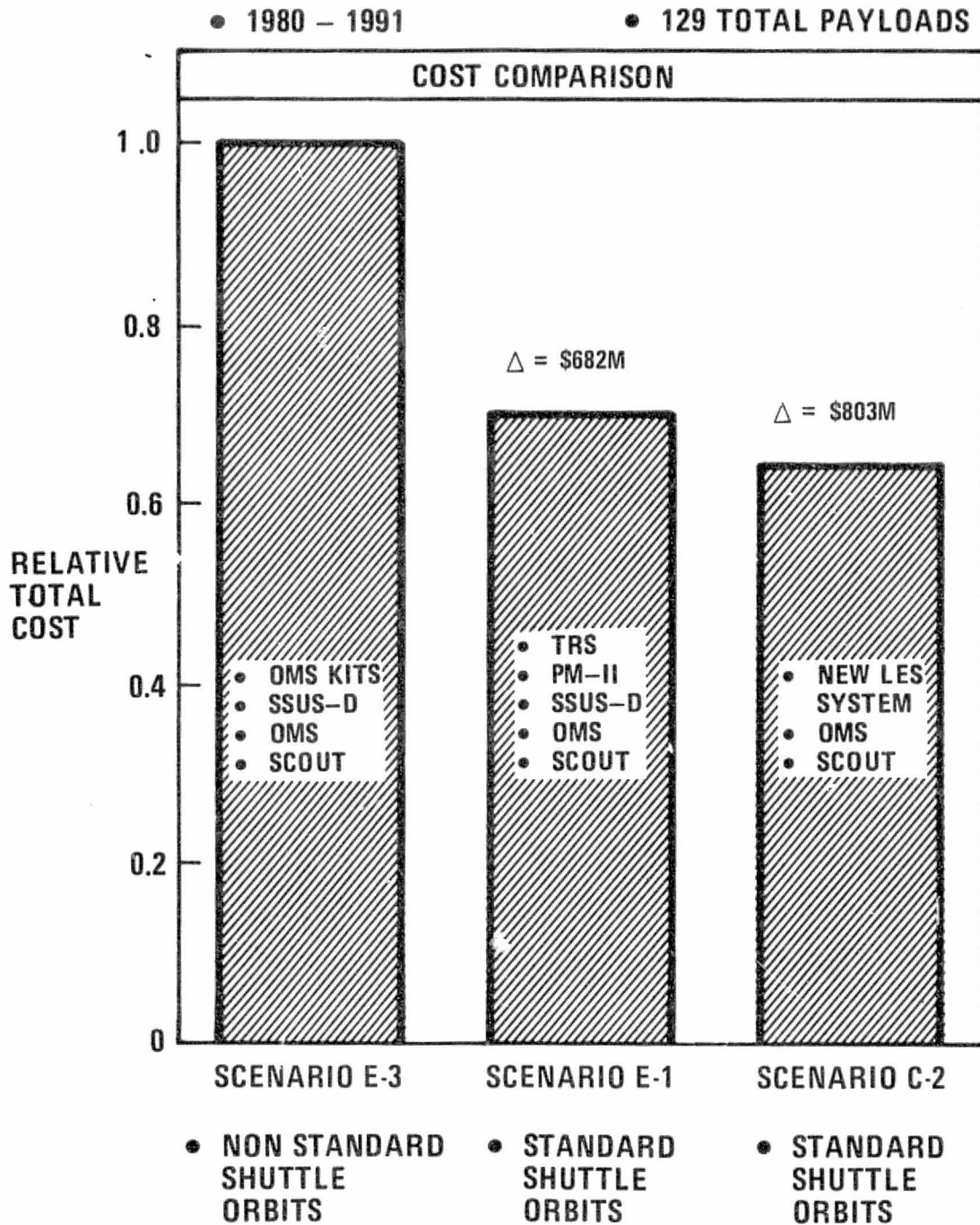


FIGURE 7.7 SUMMARY COMPARISON OF PAYLOAD DELIVERY APPROACHES

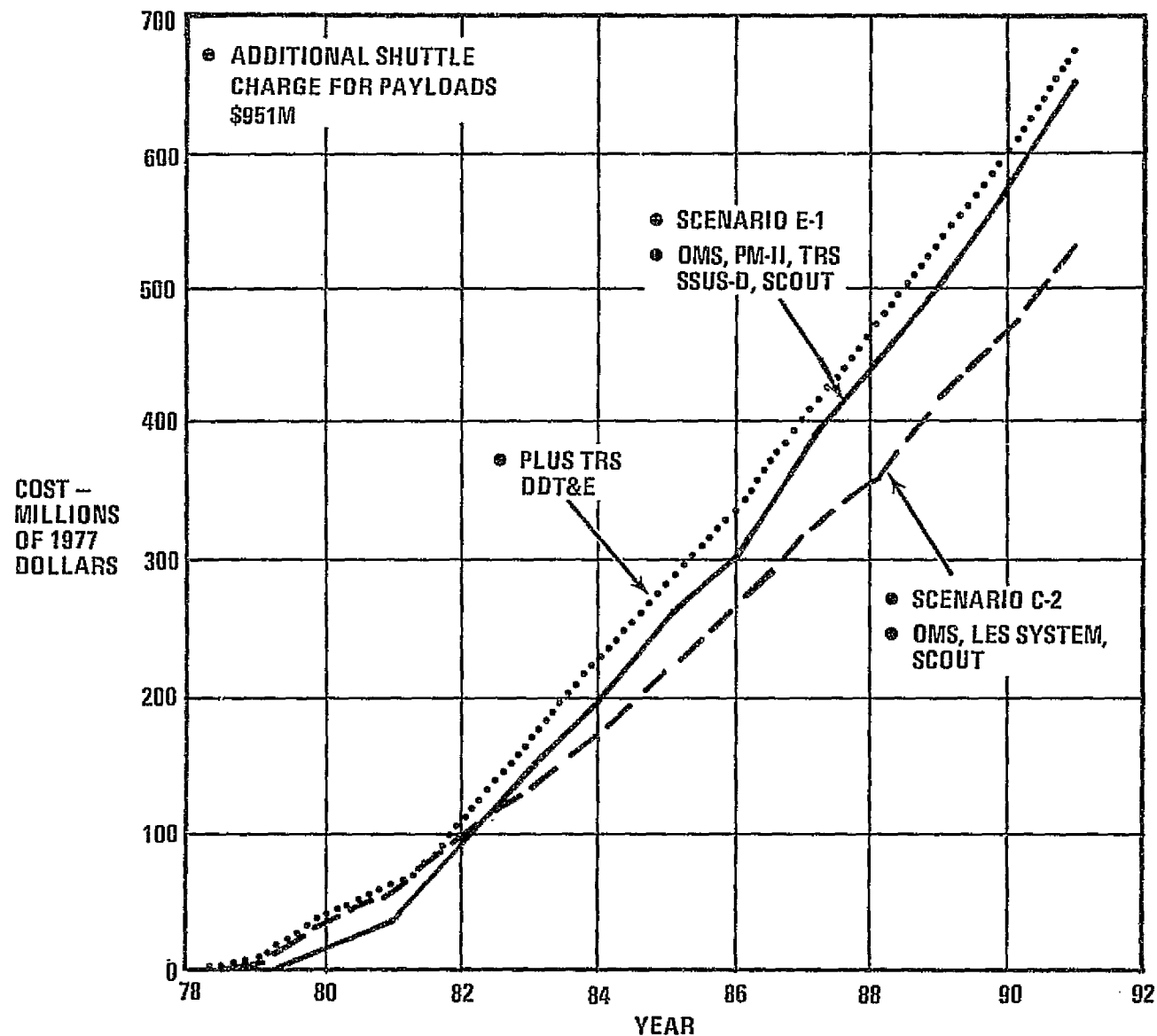


FIGURE 7.8 CUMULATIVE COST TO DELIVERY LES PAYLOAD MODEL

of \$951,224,000 (951 million) was subtracted from the total cost of both scenarios. The point in time at which the cumulative cost stream of the existing/planned system scenario crosses above the cost stream of the scenario containing the LES system is at the end of the first quarter of 1983. Cost for the existing/planned scenario over the 1978-1991 period of the study is \$652.2M without the \$951M added payload charge; similar cost for the LES system scenario is \$531.1M. Thus, the difference between costs for the two systems is \$121.1M, or over 19 percent in favor of the LES system scenario. If the DDT&E costs for TRS (including one proto flight unit) were added to the existing/planned scenario costs, the total cost increases to \$678.1M; with this added cost at the beginning of the life cycle, the cost stream of this scenario is higher than that of the LES system scenario throughout the time frame of the LES payload mission model. This additional cost would indicate a net benefit of \$147.0M (21.7%) to the LES system scenario in absolute 1977 dollars.

This cost benefit occurs over the period of time 1979 through 1991. The present value of the deferred costs and benefits of the two approaches was estimated by the application of a social discount rate as described in Reference 58. The discount rate is the assumed amount of cost benefits needed to outweigh what the tax payer might have earned with the money if it had been left with him, not extracted by the government. Each year expected yearly cost for each of the two approaches being evaluated, E-1 and C-2, was multiplied by the social discount rate and then summed over all future years to give a program present value cost. The net present value cost benefit for a specified discount rate was obtained by the net difference between the two approaches. The discount rate was varied to determine the internal rate of return which is the discount rate at which the net present value becomes zero.

When present value techniques were considered by applying a 10% social discount rate to the life cycle cost streams of these two scenarios, shown in Tables 7-XXV and 7-XXVI, the cumulative discounted cost streams of Figure 7.9 results. Here the total discounted life cycle cost of the existing/planned scenario is \$277.2M, and of the LES system scenario C-2 is \$233.7M

TABLE 7-XXV
SCENARIO C-2 COST SCHEDULE
(ALL COSTS THOUSANDS)

CONFIGURATION/YEAR	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
SCENARIO C2														
DDT&E	1,303	14,620	9,136	1,045										26,104
ANNUAL OPERATIONS		4,811	4,811	6,509	2,315	2,315	2,315	2,315	2,315	2,315	2,315	2,315	2,315	36,966
INTEGRAL QMS														
NUMBER OF LAUNCHES	0	0	0	0	1	1	1	1	3	2	2	2	3	16
PRODUCTION				0	0	0	0	0	0	0	0	0	0	0
OPERATIONS (UNIT)				0	0	0	0	0	0	0	0	0	0	0
SHUTTLE CHARGE-PAYLOAD				0	11,859	20,933	20,933	11,859	53,725	32,793	41,866	32,793	53,725	280,486
-STAGE & ASE				0	0		0	0	0		0	0	0	
OTHER CHARGES				0	200	200	200	200	600	400	400	400	600	3,200
TOTAL - INTEGRAL QMS	0	0	0	0	12,059	21,133	21,133	12,059	54,325	33,193	42,266	33,193	54,325	293,686
MODULAR 4 TANK HORIZONTAL BIPROP														
NUMBER OF LAUNCHES	0	0	0	4	5	5	9	7	10	8	9	9	10	76
PRODUCTION				7,026	8,783	8,782	15,809	12,296	17,565	14,052	15,809	15,808	17,565	133,494
OPERATIONS (UNIT)				1,243	1,554	1,554	2,796	2,175	3,107	2,486	2,795	2,796	3,107	23,613
SHUTTLE CHARGE-PAYLOAD				10,489	29,249	29,800	68,488	52,324	74,179	53,110	68,330	64,186	72,270	532,426
-STAGE & ASE				7,175	12,888	7,623	15,187	10,313	16,531	11,657	15,187	13,003	16,531	126,097
TOTAL - 4 TANK HORIZONTAL	0	0	0	25,933	52,474	47,759	102,280	77,108	111,382	91,305	102,121	95,793	109,473	815,630

TABLE 7-XXV (CONTINUED)

CONFIGURATION/YEAR	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
MODULAR 8 TANK HORIZONTAL BIPROP														
NUMBER OF LAUNCHES	0	0	0	0	1	0	1	2	2	2	2	2	1	13
PRODUCTION					2,135	0	2,135	4,269	4,270	4,269	4,269	4,269	2,135	27,751
OPERATIONS (UNIT)					311	0	311	621	621	622	621	621	311	4,039
SHUTTLE CHARGE-PAYLOAD					12,854	0	520	25,709	13,980	25,709	13,980	25,709	12,854	131,315
-STAGE & ASE					1,345	0	6,245	2,690	5,399	2,690	5,399	2,690	1,345	27,803
TOTAL - 8 TANK HORIZONTAL	0	0	0	0	16,645	0	9,211	33,289	24,270	33,290	24,269	33,289	16,645	190,908
MODULAR 4 TANK VERTICAL BIPROP														
NUMBER OF LAUNCHES	0	0	0	0	2	2	0	1	2	1	2	1	3	14
PRODUCTION					3,544	3,544	0	1,772	3,544	1,772	3,543	1,772	5,316	24,807
OPERATIONS (UNIT)					621	621	0	311	621	311	621	311	932	4,349
SHUTTLE CHARGE-PAYLOAD					1,620	1,462	0	937	3,536	1,626	3,536	1,626	3,784	18,127
-STAGE & ASE					4,835	6,715	0	3,166	4,584	3,549	4,584	3,549	7,366	38,348
TOTAL 4 TANK VERTICAL	0	0	0	0	10,620	12,343	0	6,186	12,285	7,258	12,284	7,258	17,398	85,631
SCOUT ELV XIII														
NUMBER OF LAUNCHES	0	3	3	4	0	0	0	0	0	0	0	0	0	10
PRODUCTION		0	0	0	0	0	0	0	0	0	0	0	0	0
OPERATIONS (UNIT)		0	0	0	0	0	0	0	0	0	0	0	0	0
SHUTTLE CHARGE-PAYLOAD		0	0	0	0	0	0	0	0	0	0	0	0	0
-STAGE & ASE		0	0	0	0	0	0	0	0	0	0	0	0	0
SCOUT-LAUNCH CHARGE		13,451	12,951	16,768	0	0	0	0	0	0	0	0	0	43,170
TOTAL - SCOUT	0	13,451	12,951	16,768	0	0	0	0	0	0	0	0	0	43,170

TABLE 7-XXV (CONCLUDED)

CONFIGURATION/YEAR	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TOTAL - SCENARIO C2	1,303	32,882	26,898	50,255	94,113	83,550	134,940	130,957	204,578	167,361	183,256	171,848	200,157	1,482,096
E-1 PAYLOAD CHARGE	0	0	0	11,941	55,064	45,985	90,319	91,689	145,870	120,948	128,160	122,022	139,226	951,224
TOTAL WITHOUT E-1 PAYLOAD CHARGE (SEE NOTE)	1,303	32,882	26,898	38,314	39,049	37,565	44,621	39,268	58,708	46,413	55,096	49,826	60,931	530,874
CUMULATIVE	1,303	34,185	61,083	99,397	138,446	176,011	220,632	259,900	318,608	365,021	420,117	469,943	530,874	
PRESENT VALUE COST - TOTAL WITHOUT - PAYLOAD CHARGE (DISCOUNTED 10%)	1,077	24,705	18,372	23,790	22,042	19,277	20,816	16,653	22,634	16,267	17,555	14,433	16,045	233,666
CUMULATIVE	1,077	25,782	44,154	67,944	89,986	109,263	130,079	146,732	169,366	185,633	203,188	217,621	233,666	
NOTE: THE PAYLOAD CHARGE "COMMON COST" HAS BEEN OMITTED FROM CONSIDERATION. (SEE PARA. 7.4.5)														

TABLE 7-XXVI
SCENARIO E-1 COST SCHEDULE
(ALL COSTS IN THOUSANDS)

CONFIGURATION/YEAR	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
DDT & E														0
ANNUAL OPERATIONS	0	4,811	4,811	6,509	8,206	3,395	3,395	3,395	3,395	3,395	3,395	3,395	3,395	51,497
INTEGRAL OMS														
NUMBER OF LAUNCHES	0	0	0	0	1	1	1	1	3	2	2	2	3	16
PRODUCTION				0	0	0	0	0	0	0	0	0	0	0
OPERATIONS (UNIT)				0	0	0	0	0	0	0	0	0	0	0
SHUTTLE CHARGE - PAYLOAD				0	11,859	20,933	20,933	11,859	53,725	32,793	41,866	32,793	53,725	280,486
SHUTTLE - STAGE & ASE				0	0	0	0	0	0	0	0	0	0	0
OTHER CHARGES				0	200	200	200	200	600	400	400	400	600	3,200
TOTAL - INTEGRAL OMS	0	0	0	0	12,059	21,133	21,133	12,059	54,325	33,193	42,266	33,193	54,325	283,686
PM II														
NUMBER OF LAUNCHES	0	0	0	0	1	1	3	4	3	3	3	5	2	25
PRODUCTION					977	977	2,931	3,908	2,931	2,931	2,931	4,885	1,954	24,425
OPERATIONS (UNIT)					311	311	933	1,244	933	933	933	1,555	622	7,775
SHUTTLE CHARGE - PAYLOAD					7,124	6,486	22,644	29,768	20,734	21,371	20,734	36,892	13,610	179,363
SHUTTLE - STAGE & ASE					2,523	2,523	7,569	10,093	7,569	7,569	7,569	12,616	5,046	63,077
TOTAL PM II	0	0	0	0	10,935	10,297	34,077	45,013	32,167	32,804	32,167	55,948	21,232	274,640

TABLE 7-XXVI (CONTINUED)

CONFIGURATION/YEAR	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
SCOUT														
NUMBER OF LAUNCHES	0	3	3	4	1									11
PRODUCTION		0	0	0	0									0
OPERATIONS (UNIT)		0	0	0	0									0
SHUTTLE CHARGE - PAYLOAD		0	0	0	0									0
SHUTTLE - STAGE & ASE		0	0	0	0									0
SCOUT LAUNCH CHARGE		13,451	12,951	16,768	3,817									46,987
TOTAL - SCOUT	0	13,451	12,951	16,768	3,817									46,987
INTEGRAL OMS + SSUS-D														
NUMBER OF LAUNCHES							1	0	1	0	1	0	0	3
PRODUCTION							2,426		2,426		2,426			7,278
OPERATIONS (UNIT)							1,200		1,200		450			2,650
SHUTTLE CHARGE - PAYLOAD							4,895		1,057		1,056			7,008
SHUTTLE - STAGE & ASE							4,497		2,933		2,934			10,364
OTHER CHARGES							200		200		200			600
TOTAL INT OMS + SSUS-D							13,218	0	7,816	0	7,066	0	0	28,100

TABLE 7-XXVI (CONTINUED)

CONFIGURATION/YEAR	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TRS 2-TANK														
NUMBER OF LAUNCHES	0	0	0	4	5	6	5	4	9	6	8	5	11	62
PRODUCTION				13,156	2,695	3,234	2,695	2,156	4,851	3,234	4,312	2,695	5,929	44,957
OPERATIONS (UNIT)				1,244	1,555	1,866	1,555	1,244	2,799	1,866	2,488	1,555	3,421	19,593
SHUTTLE CHARGE - PAYLOAD				11,941	23,231	18,566	33,768	24,357	57,504	41,079	51,654	26,632	59,041	347,773
SHUTTLE - STAGE & ASE				14,042	26,309	37,696	26,299	17,562	40,338	29,793	36,828	26,268	54,402	309,557
TOTAL TRS 2 TANK	0	0	0	40,383	53,790	61,362	64,317	45,319	105,492	75,972	95,282	57,170	122,793	721,880
TRS 4 TANK														
NUMBER OF LAUNCHES	0	0	0	0	1	0	1	2	1	2	1	2	1	11
PRODUCTION					11,614	0	614	1,228	614	1,228	614	1,228	614	17,754
OPERATIONS (UNIT)					311	0	311	622	311	622	311	622	311	3,421
SHUTTLE CHARGE - PAYLOAD					12,850	0	8,079	25,105	12,850	25,705	12,850	25,705	12,850	136,594
SHUTTLE - STAGE & ASE					3,509	0	3,509	7,019	3,509	7,019	3,509	7,019	3,509	38,602
TOTAL TRS 4 TANK	0	0	0	0	28,284	0	12,513	34,574	17,284	34,574	17,284	34,574	17,284	196,371

TABLE 7-XXVI (CONCLUDED)

CONFIGURATION/YEAR	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TOTAL COST - SCENARIO E-1	0	18,262	17,762	63,660	117,091	96,187	148,653	140,360	220,479	179,938	197,460	184,280	219,029	1,603,161
TOTAL PAYLOAD CHARGE	0	0	0	11,941	55,064	45,985	90,319	91,689	145,870	120,348	128,160	122,022	139,226	951,224
TOTAL WITHOUT PAYLOAD CHARGE	0	18,262	17,762	51,719	62,027	50,202	58,334	48,671	74,609	56,990	69,300	62,258	79,803	651,937
CUMULATIVE	0	18,262	36,024	87,743	149,770	199,972	258,306	306,977	381,586	440,576	509,876	572,134	651,937	
PRESENT VALUE COST	0	13,721	12,132	32,113	35,012	25,762	27,213	20,641	28,765	20,676	22,081	16,034	21,015	277,165
TOTAL WITHOUT PAYLOAD (DISCOUNTED 10%)														
CUMULATIVE	0	13,721	25,853	57,966	92,918	118,740	145,953	166,594	195,359	216,035	238,116	256,150	277,165	

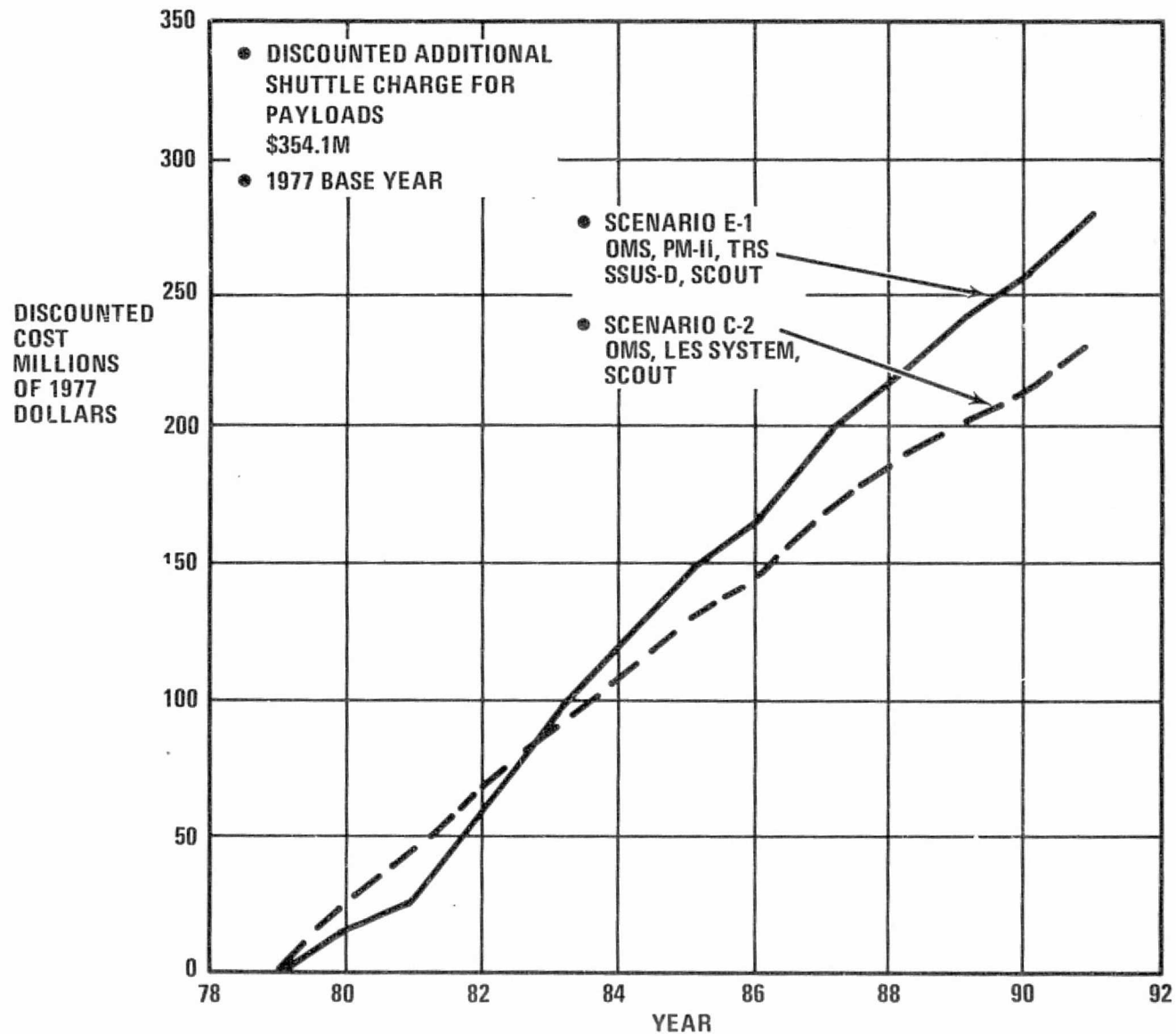


FIGURE 7.9 DISCOUNTED CUMULATIVE COST TO DELIVER LES PAYLOAD MODEL

a \$43.5M or 16 percent benefit to the LES system scenario. Discounted additional Shuttle charges common to both scenarios is \$354M. The point in time at which the cost streams of the two scenarios cross occurs in the second quarter of 1983.

Some economic analysts consider the 10 percent discount rate a conservative criterion to apply to public investment projects of this type and argue in favor of a 5 to 7.4 percent rate as more realistic for analysis in constant year dollars. Figure 7.10 illustrates the effect of applying social discount rates to the life cycle net benefit streams of these two scenarios. The net present value of the LES system scenario over the existing/planned system scenario increases markedly as the discount rate decreases to the undiscounted value of \$121.1M. As the discount rate is increased there is still a net present value of \$18M at a 20 percent rate.

The internal rate of return obtained by the LES system scenario investment relative to the existing/planned scenario is greater than 40%.

A comparison of the payload/stage/ASE charges to the payload user for Shuttle usage for the two scenarios shows \$1376.8M for the existing/planned system scenario and \$1157.8M for the LES system scenario - a \$219.0M benefit to the latter scenario in absolute 1977 dollars. This benefit is indicative of a more efficient Shuttle utilization.

In summary, within the ground rules of the study, the scenario containing the new LES system emerges as the dominant economic choice considering the criterion of scenario evaluation; i.e., net benefits, internal rate of return, and significant reduction in Shuttle user charges to the payload user.

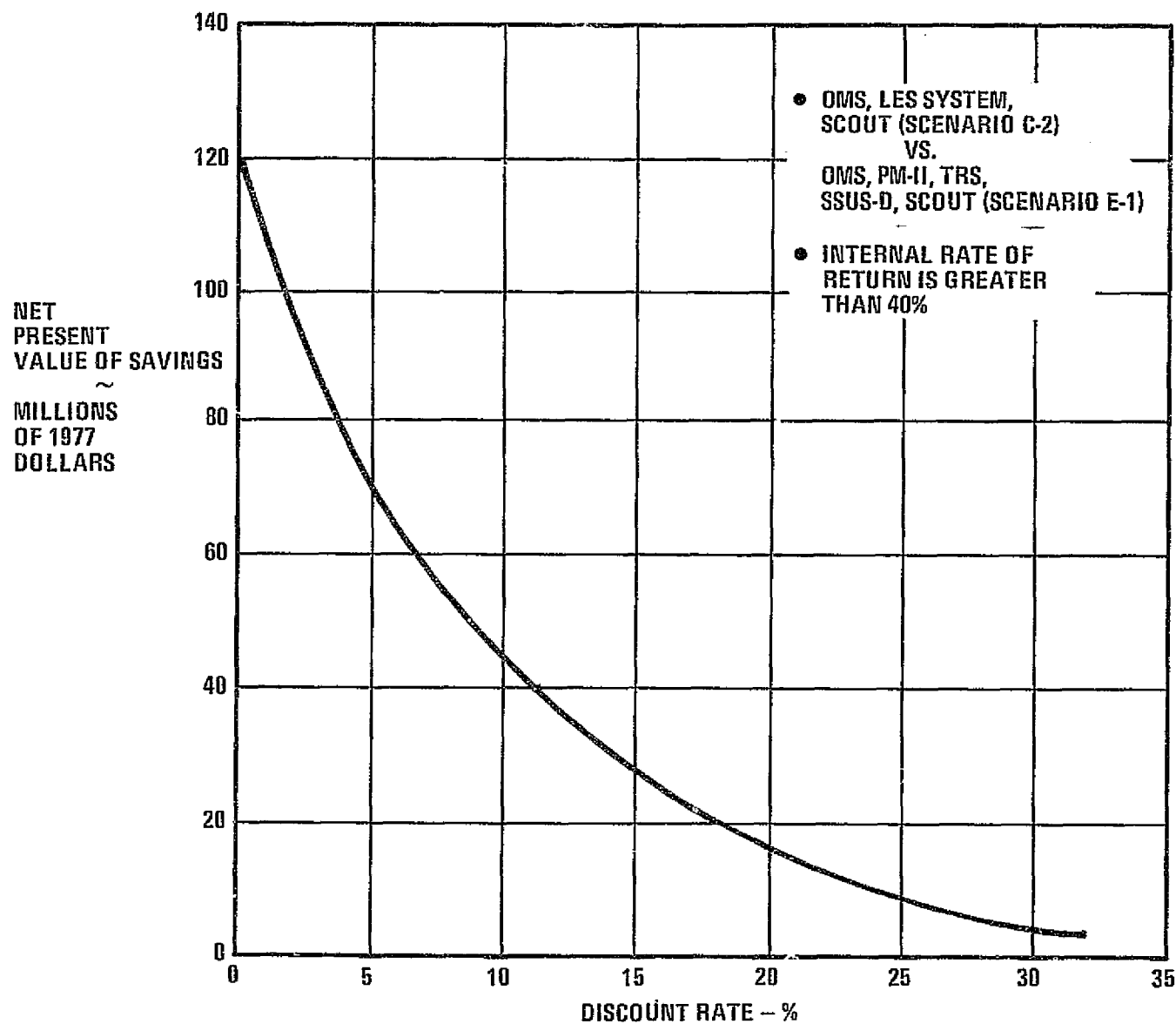


FIGURE 7.10 DISCOUNTED COST BENEFITS

8.0 TASK 7: RECOMMENDATIONS

The most cost effective approach to accomodate the LES payload mission model and the LES regime is recommended in this section. The recommended approach, ground and flight operations definition, Shuttle user charge implications, and implementation plans are followed by additional recommendations that are logical results of the study.

8.1 RECOMMENDED APPROACH

The approach selected in Task 6 as most cost effective to accomodate the LES payload mission model consists of integrated OMS, a new low energy stage system and Scout through 1982. This is the recommended approach. Recommended start date is fiscal year 1980 (Oct. 1979) with the first launch from the shuttle in the third quarter of fiscal 1982 (June 1982). The Scout launch vehicle should continue operation from WTR until the shuttle with the low energy stage is operational from WTR in 1983. Additional studies are recommended to evaluate the low energy stage system as a reuseable system and as an integrated spacecraft support system.

8.1.1 Existing Systems

The two existing systems are (1) the Shuttle with integral OMS to deliver four observatories and telescopes to their orbits (16 payload flights) and (2) the Scout expendable launch vehicle to deliver the seven payloads (10 payload flights) designated in the payload model as Scout class payloads. All of these Scout payloads are launched in the 1980-1983 time frame. The new low energy stage concept accommodates the rest of the payloads of the LES model.

8.1.1.1 Shuttle Integral OMS - The application of this existing system to deliver low energy payloads consists of either (1) the Orbiter maneuvering from its standard orbit altitude of 296 km (160 nm) to the destination orbit of the payload or (2) the Shuttle boosting directly to the destination altitude to deliver a payload. There is currently planned an additional STS charge for delivery to a nonstandard orbit. For this study that charge was considered to be \$200,000 based on discussions with cognizant NASA Headquarters personnel.

The performance capability of the Orbiter with integral OMS in a 28.5° orbit from ETR is shown in Figure 8.1, along with capabilities of the

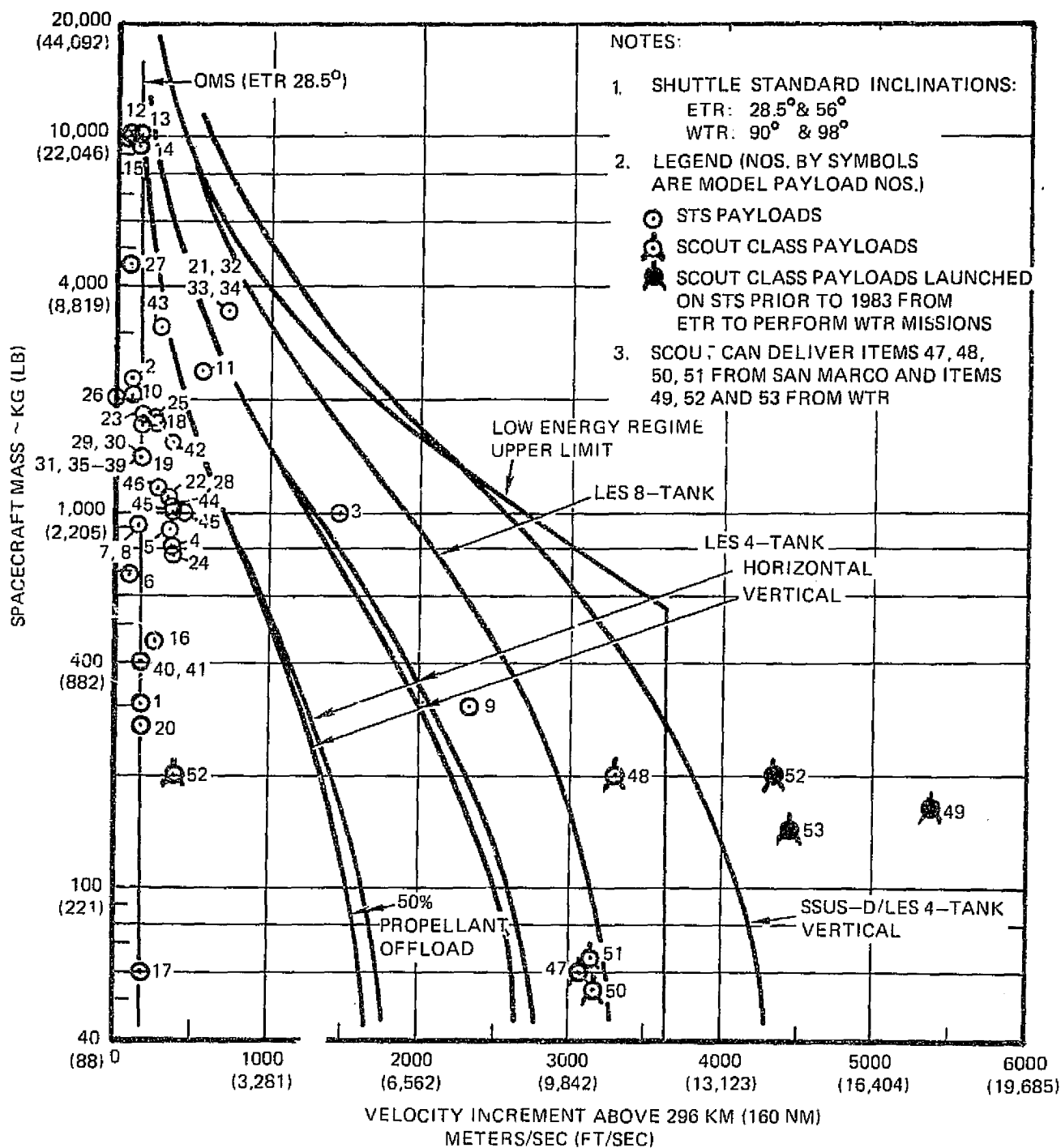


FIGURE 8.1 PERFORMANCE CAPABILITIES OF RECOMMENDED APPROACH

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other elements of the recommended approach, against the requirements of the payloads of the LES mission model. Integral OMS was used to accommodate four of the payloads of the model encompassing 16 payload flights (12%). These payloads were large observatories and a space telescope that occupied a large part of the cargo bay. User costs were based on the charged flight charge policy. Launch schedule, payload and destination orbit characteristics, and Shuttle launch sites for these four payloads are shown in Table 8-I (line items 12, 13, 14 and 15 in the table).

Definition of airborne and ground support equipment and Shuttle operations requirements for this mode of payload delivery are contained in STS standard documentation.

8.1.1.2 Scout Expendable Launch Vehicle - The Scout expendable launch vehicle operating from either WTR or the San Marco launch site delivers seven payloads (10 flights) of the LES payload mission model (8%) designated as Scout class payloads to their destination orbits. Launch schedules, payload and destination orbit characteristics, and launch sites for these payloads are shown in Table 8-I (line items 47 through 53). Payloads launched from San Marco are scheduled for 1980 and 1981; the other payloads are launched from WTR in 1980 through 1982. The Transit launch in 1983 can be accommodated by the Shuttle and the low energy stage from WTR.

Ground support equipment and operations requirements are defined as a part of the standard Scout launch vehicle documentation.

8.1.2 Low Energy Stage System

A new low energy stage system is recommended to deliver the remaining 80% of the payloads of the LES model and to provide capability to deliver potential future payloads with requirements in the low energy regime. The system consists of a modular bipropellant propulsion system comprising two arrangements of four and eight propellant tanks installed horizontally in the Orbiter and one four-tank arrangement installed vertically in the Orbiter. Airborne and ground support equipment are included as a part of the system.

TABLE 8-I LES PAYLOAD MISSION MODEL

MISSION NAME	SPONSOR	LAUNCH SCHEDULE														LES ^(b) PAYLOAD TOTAL	SPACECRAFT PARAMETERS		STS CONFIG- URATION	DELIVERY ORBIT		LAUNCH SITE	PAYLOAD CODE	PAYLOAD CLASS
		#0	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13		MASS kg	LENGTH DIA. m		APOGEE PERIGEE km	INCL. deg.			
1. Extreme UV Explorer	NASA-OSS			1												1	310	0.9/ 4.6	FF	550/ 550	28.5	ETR	AAAA01	P+A EX
2. High Energy Explorer	NASA-OSS				1				1		1					4	2270	4.6/ 4.6	FF	463/ 463	28.5	ETR	AAAA02	P+A EX
3. Low Energy Explorer	NASA-OSS									1	1					2	1000	1.8/ 1.4	FF	556/ 556	44.9	ETR	AAAA03	P+A EX
4. Cosmic Background Explorer (COBE)	NASA-OSS					1				1		1				3	816	2.9/ 4.4	FF	900/ 900	99	WTR	AAAF01	P+A EX
5. IR Astronomy Explorer	NASA-OSS									1		1				2	900	2.5/ 1.5	FF	700-900 Circ.	98-99 ^a	WTR	AAAF02	P+A EX
6. Electrodynamics Explorer A	NASA-OSS								1				1			2	680	1.8/ 1.4	FF	500/ 204	90	WTR	AAAF03	P+A EX
7. Gravity Probe B (Relativity)	NASA-OSS									1						1	910	3.6/ 2.2	FF	520/ 520	90	WTR	AGAF02	S// P+A/FF
8. Advanced Relativity	NASA-OSS													2		2	910	3.6/ 2.2	FF	520/ 520	90	WTR	AGAF03	S// P+A/FF
9. Plasma Probe B	NASA-OSS						1									1	300	3.0/ 4.6	S-D	29,600/ 370	90	WTR	AGAF04	S// P+A/FF
10. Solar Maximum	NASA-OSS				R		1		R	1	R	1	R	1		4	2047	4.0/ 2.2	MMS	463/ 463	28.5	ETR	AEAB01	S// P+A OBS
11. Upper Atmosphere Research Sat (UARS)	NASA-OSS						1									1	2400	5.0/ 4.0	MMS	400-625 circ	52	ETR	AEAB02	S// P+A OBS
12. Gamma Ray Observatory	NASA-OSS				1		R	1	V	V	R	1	V			6	10000	7.3/ 4.3	FF	400/ 400	28.5	ETR	ACAA01	LEG P+A OBS
13. 1.2M X-Ray Observatory	NASA-OSS						1		R	1	V	V	R	1		5	10000	12.4/ 4.3	FF	500/ 500	28.5	ETR	ADAA01	LEG P+A OBS
14. Space Telescope	NASA-OSS					1		R	1		V	V				4	9400	12.9/ 4.37	FF	500/ 500	28.5	ETR	ABAA01	LEG P+A OBS
15. Large Solar Obs.	NASA-OSS											1				1	9825	16.2/ 4.6	FF	350/ 350	28.5	ETR	ADAA02	LEG P+A OBS
TOTALS(LES PAYLOADS) ^(b)				1	2	3	4	2	7	4	5	4	7			39								

(a) Sun-synchronous orbit
(b) Retrievals not included.

TABLE 8-I LES PAYLOAD MISSION MODEL (CONT'D)

		LAUNCH SCHEDULE														LES(c) PAYLOAD TOTAL	SPACECRAFT PARAMETERS			DELIVERY ORBIT						
MISSION NAME		SPONSOR			80	81	82	83	84	85	86	87	88	89	90	91	92		MASS kg	LENGTH DIA. m	STS CONFIG- URATION	APOGEE PERIGEE km	INCL. deg.	LAUNCH SITE	PAYLOAD CODE	PAYLOAD CLASS
NASA-OA																										
16.	Earth Radiation Budget Sats (ERBS)	NASA-OSTA					1											1	454	4.3/ 2.1	FF	704/ 704	56	ETR	APCA01	LG/ APP/FF
17.	Halogen OCC Sat	NASA-OSTA						1										1	60	0.8/ 0.8	FF	593/ 593	56	ETR	ARCA01	SM/ APP/FF
18.	LANDSAT D	NASA-OSTA						R1		R		1				R1		3	1700 ^a	4.3/ 2.2	MMS	704/ 704	98.2	WTR	BECB01	MED/ APP/OBS
19.	Soil Moisture	NASA-OSTA							1									1	1400	4.6/ 1.8	FF	570/ 570	98	WTR	APCA02	LG/ APP/FF
20.	MAGSAT	NASA-OSTA							1									1	270	0.9/ 0.9	FF	344/ 344	99	WTR	ARCA02	SM/ APP/FF
21.	SEASAT B	NASA-OSTA					1											1	3400	8.0/ 3.0	MMS	740/ 740	85	WTR	ACQF03	MED/ APP/FF
22.	TIROS O	NASA-OSTA								1								1	1100/ 1600	7.0/ 3.6	FF or MMS	830 or 1700 ^b	98 or 103	WTR	ACQB01	MED/ APP/FF
23.	Environmental Monitor Sat (LOW)	NASA-OSTA								1	1					1		3	1600- 2000	5.2/ 2.3	MMS	590/ 590	56	ETR	ACQB02	MED/ APP/FF
24.	Earth Survey	NASA-OSTA										1		1				2	772	3.0/ 1.5	FF	910/ 910	100	WTR	ARCF02	SM/ APP/FF
25.	Global Resources Map Info System	NASA-OSTA							1									1	1600- 2000	6.1/ 4.0	MMS	700/ 700	98.2	WTR	APCB02	LG/ APP/FF
26.	GRAVSAT	NASA-OSTA							1				1					2	2000	2.2/ 4.0	MMS	300/ 300	90	WTR	APCB01	LG/ APP/FF
TOTAL							1	3	3	3	1	2	1	1	2			17								
NASA-OAST																										
27.	Space Technology Research Satellite	NASA-OAST										1		R1		R1		3	4500	3.6/ 2.4	FF	426/ 426	28.5	ETR	AMBA01	MED/TECH OBS
TOTAL												1		1		1		3								
NASA SUMMARY																										
OSS Total							1	2	3	4	2	7	4	5	4	7		39								
OA Total							1	3	3	3	1	2	1	1	2			17								
OAST Total												1		1		1		3								
NASA TOTAL							2	5	6	7	3	10	5	7	6	8		59								

(a) Includes PM-1 propulsion module to be used for on-orbit attitude control and stationkeeping only.

(b) Circular orbit.

(c) Retrievals not included.

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- (a) Sun-synchronous orbit
- (b) Includes PMS PM-1
- (c) Retrievals not included.
- (d) Circular orbit

TABLE 8-I LES PAYLOAD MISSION MODEL (CONCLUDED)

		LAUNCH SCHEDULE												LES (c) PAYLOAD TOTAL	SPACECRAFT PARAMETERS		STS CONFIG- URATION	DELIVERY ORBIT		LAUNCH SITE	PAYLOAD CODE	PAYLOAD CLASS	
MISSION NAME	SPONSOR	80	81	82	83	84	85	86	87	88	89	90	91	92	MASS kg	LENGTH DIA. m		APOGEE PERIGEE km	INCL. deg.				
FOREIGN																							
40. Canadian Scientific	Canada					1							1		2	400	1.5/ 1.2	FF	550/ 550	90	WTR	AZLA01	SM/F/FF
41. European Scientific	Europe								1			1	1		3	400	1.5/ 1.2	FF	550/ 550	28.5	ETR	AZLA02	SM/F/FF
42. Canadian Microwave	Canada						1						1		2	1523	4.0/ 1.5	FF	909/ 909	99	WTR	BAPF01	MED/F/FF
43. Sea Monitor	Canada									1					1	3110	9.0/ 4.0	FF	800/ 800	98.5	WTR	BAPG01	MED/F/FF
44. Earth Resources Foreign (low)	Foreign								1			1	1		3	1042	8.2/ 1.5	FF	910/ 910	99	WTR	AZNF03	SM/F/FF
TOTAL						1	1		2	1	2		4		11								
DoD (a)																							
45. USAF Space Test Program	DoD	1	1	1	1	1	1	1	1	1	1	1	1		12	910- 1000	1.0/ 4.0	FF	500-1000 Circ.	28.5- 100	ETR ^d WTR ^d	BT	DoD
46. USAF Meteorological Satellite	DoD				1	1	1	1	1	1	1	1	1		9	1150	6.0/ 3.0	FF	750/ 750	98.4	WTR	BT	DoD
TOTAL		1	1	1	2	2	2	2	2	2	2	2	2		21								
PLANNED SCOUT																							
47. San Marco D ₀	OSS	1													1	50-60	1.5/ 0.8	Scout	27,000/ 420	2.9	SM		Scout
48. San Marco D ₁	OSS	1													1	200	1.5/ 0.8	Scout	800/230	2.9	SM		Scout
49. Solar Mesosphere Explorer	OSS		1												1	165	1.5/ 0.8	Scout	500/500	97	WTR		Scout
50. AMPTE A	OSS		1												1	54	1.5/ 0.8	Scout	20 r / (b) e 200	2.9	SM		Scout
51. AMPTE B	OSS			1											1	66	1.5/ 0.8	Scout	8 r / (b) e 200	2.9	SM		Scout
52. Transit	DoD	1	1	1	1										4	170-200	1.5/ 0.8	Scout	1000/ 1000	90	WTR		DoD
TOTAL		3	3	2	1										9								
POTENTIAL SCOUT																							
53. Canadian Scientific				2											2	145	1.5/ 0.8	Scout	550/ 550	90	WTR	AZLA01	Scout

(a) Battelle 3/78 best estimate of unclassified low energy DoD missions.
 (b) 296 if Shuttle launched.

(c) Retrievals not included.

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8.1.2.1 System Description - The new propulsion approach, developed in Volume III, paragraph 4.0, consists of a modular arrangement of propellant tanks and structure to produce a stage system that can be adapted to a wide variety of payload sizes, shapes and velocity requirements. The modularity and the installation variations are depicted in Figure 8.2.

The LES System is baselined around the 8-tank version. This is used for relatively heavy payloads or to meet very high velocity change requirements. As shown in the figure, 4 modules can be removed to create a 4-tank version for intermediate requirements. Removal and re-arrangement of two additional modules creates a vertical installation capability for the four tank version. If in the future an "adaptation" of the LES to SSUS-D is needed for spacecraft not now in the LES payload model, the 4-tank vertical version can be adapted as depicted in Figure 8.6 shown and discussed at a later point in this report.

A weight summary for each version of the Modular Bipropellant is shown in Table 8-II.

TABLE 8-II MODULAR BIPOPELLANT WEIGHT SUMMARY

Kg (lb)

	MODULAR 8 TANK	MODULAR 4 TANK	MODULAR 4 TANK VERTICAL	MODULAR 4 TANK VERTICAL/SSUS-D
STAGE INERTS	681.7 (1503)	432.9 (955)	464.3 (1024)	558.7(1232)
CONSUMABLES	1669.2 (3680)	829.2 (1828)	829.2 (1828)	747.5(1648)
STAGE IGNITION	2350.9 (5183)	1262.1 (2783)	1293.5 (2852)	1306.2(2880)
ADAPTATION (SSUS-D)	- -	- -	- -	1754.5(3868)
TOTAL STAGE WEIGHT	2350.9 (5183)	1262.1 (2783)	1293.5 (2952)	3060.7(6748)

8.1.2.2 System Performance - The performance capabilities of the three versions of the bipropellant propulsion, modular low energy stage (LES) system are shown in Figure 8.1 relative to the requirements of the payloads of the low energy mission model and to the low energy regime. Capabilities of the horizontally mounted and vertically mounted 4-tank versions are shown with

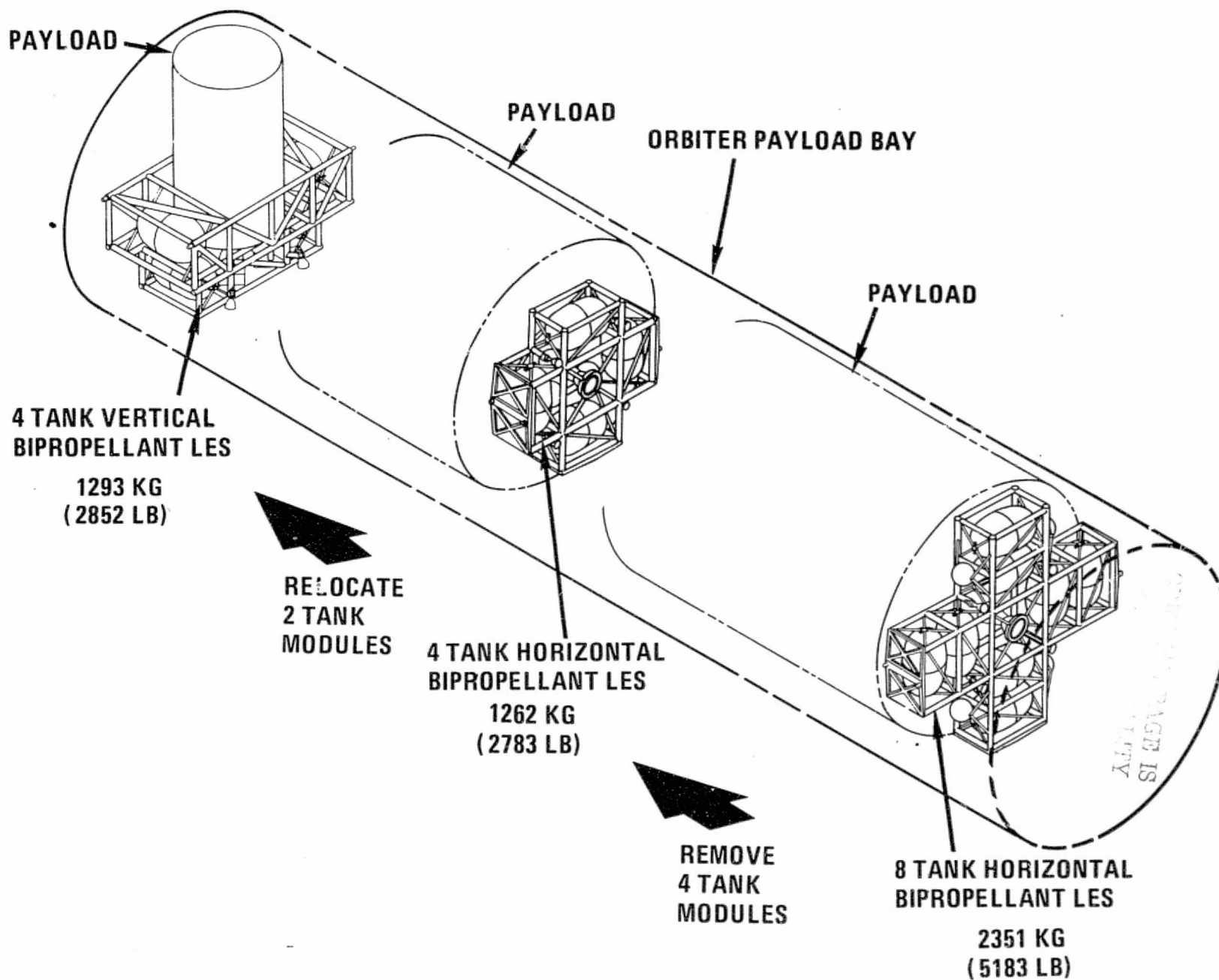


FIGURE 8.2 MODULE ARRANGEMENTS – BIPROPELLANT LES

full fuel tanks and with fuel off-loaded to 50% of capacity. The LES system accommodates the remaining 42 payloads (103 flights) of the LES payload mission model (shown in Table 8-I) not accommodated by the Shuttle with integral OMS or the Scout launch vehicle as defined in preceding paragraphs. By 1983 when the Shuttle is operational from WTR and after the Scout class payloads of the LES model have been delivered to orbit, the 4- and 8-tank versions of the LES system can accommodate all of the remaining payloads of the model; although the 3 observatory and one telescope payloads (16 flights) would still likely be delivered by the Shuttle with integral OMS.

Performance capabilities of the 4- and 8-tank versions of the LES system cover 85% of the low energy regime and encompass the requirements for all payloads of the LES model after 1983. If, in the future, payloads are defined with mission requirements in the low energy regime beyond the capability of the 8-tank version, an "adaptation" of the vertical 4-tank version to the SSUS-D can increase the regime coverage to 99.6% (Figure 8.1). Based on the distribution of performance requirements of the payloads of the LES model the probability of future payloads with such higher energy requirements would appear to be quite low.

8.1.2.3 Airborne Support Equipment - A modular cradle set concept for the LES system (developed in Volume III paragraph 5.0) accommodates payloads with lengths not greater than 9 meters (29.53 feet), diameters not greater than 4 meters (13.12 feet), and mass not greater than 4500 kg (9921 pounds). Components from existing or planned Shuttle or upper stage cradles were utilized where practical. Modular cradle component parts of the set are listed in Table 8-III from which any of four cradles can be assembled. Figure 8.3 shows one of these cradles with a payload and LES installed. The code numbers on the figure identify the cradle parts shown in Table 8-III. Modular cradle sizes accommodate the other payloads as shown in Figure 8.4. It is planned to mount payloads larger than the 9 by 4 meters directly to the cargo bay attach points and cantilever the stage to the aft end of the payload.

The ASE avionics equipment and installation concept developed for the LES system provides the physical and electrical interfaces between LES/cradle/payload and Orbiter equipment. Figure 8.5 shows the cradle, avionics

TABLE 8-III LES ASE CRADLE ASSEMBLIES PARTS LIST

PART NO.	PART DESCRIPTION	QUANTITY PER SET	CRADLE ASSY. #1 SMALL HORIZONTAL QUANT/ASSY	CRADLE ASSY. #2 MEDIUM HORIZONTAL QUANT/ASSY	CRADLE ASSY. #3 LARGE HORIZONTAL QUANT/ASSY	CRADLE ASSY. #4 VERTICAL QUANT/ASSY.
1	Cradle I (10" wide)	2	1	2		2
2	Cradle II (14" wide)	2	1	2	2	
3	Walking Beam (14" wide)	1		1	1	
4	Cradle Filler	1	1	1		
5	Cradle Extender - LH	1	1	1	1	
6	Cradle Extender - RH	1	1	1	1	
7	Filler Adapter - LH	1	1	1		
8	Filler Adapter - RH	1	1	1		
9	Filler Adapter - Bottom	1	1	1	1	
10	Deploy Mechanism Base	2	2			
11	Rod Assy - Adjustable 60" to 100"	4	4	(4)	(4)	
12	Rod Assy - Fixed 38"	4			(4)	4
13	Rod Coupler - Fixed 20" Length	4			(4)	
14	Rod Assy - Adjustable 12" to 20"	4		(4)		
15	Rod Assy - Adjustable 30" to 36"	4		(4)		
16	Rod Assy - Adjustable 36" to 60"	4		(4)	(4)	
17	Latch Mech. - Type A (NMS/FSS Type)	8	5	8	6	5
18	Latch Mech. - Type B (Orb Deployable Type)	2			2	
19	Latch Spacer	6	5	6		
20	Longeron Trunnion	4	4	4	4	4
21	Keel Trunnion	2	1	2	2	1
22	Deploy Mechanism #1 - Mechanical Spring Pkg	2	2			2
23	Deploy Mechanism #2 - Multiple Spring Pkg	1		1		
24	Deploy Mechanism #3 - Electro/Mech Mechanism	1			1	
25	Deploy Mechanism - Base-Fixed	1				1
26	Deploy Mechanism - Base-Moveable	1			1	
27	Walking Beam - Pivot Assembly	1		1	1	
28	Latch Shim - Type A	6		3	6	5
29	Latch Shim - Type B	2			2	
30	Vertical Launch - Walking Beam - Assy.	2				2
31	Filler Adapter - Side	4				4
32	Filler Adapter - Bottom	1				1
33	Cross Brace Assembly	4				4
TOTALS		85	31	40	39	35

NOTE: () OPTIONAL DEPENDING ON PAYLOAD LENGTH

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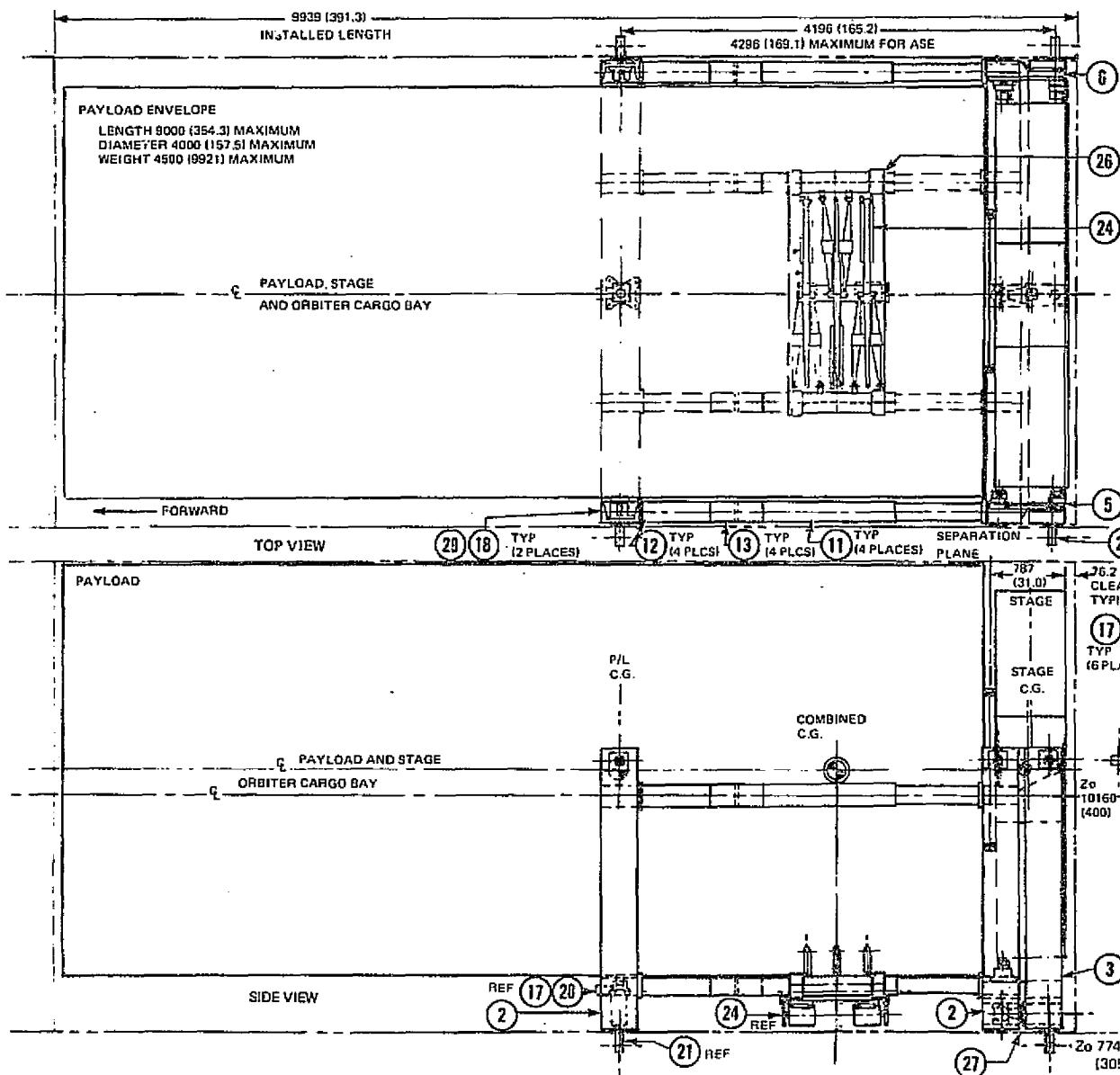


FIGURE 8.3 LARGE HORIZONTAL LES/PAYLOAD INSTALLATION

CRADLE ASSEMBLY #3

STAGE	TOTAL ASE WEIGHT	
BIPROPELLANT:		
4 TANK	1717	(3785)
8 TANK	1541	(3397)
MONOPROPELLANT:		
2 TANK	1717	(3785)
8 TANK	1541	(3397)

NOTE: DIMENSIONS IN MILLIMETERS (INCHES)
WEIGHTS IN KILOGRAMS (POUNDS)

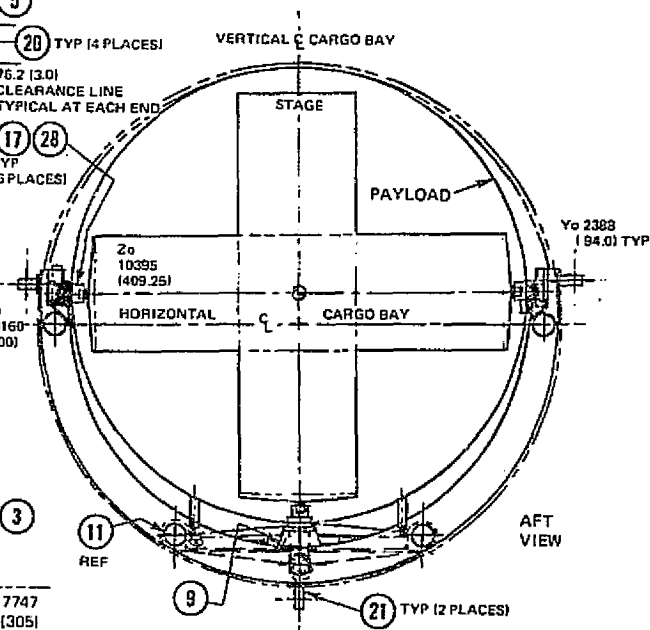


FIGURE 8.4 MODULAR BIROPELLANT LES SYSTEM

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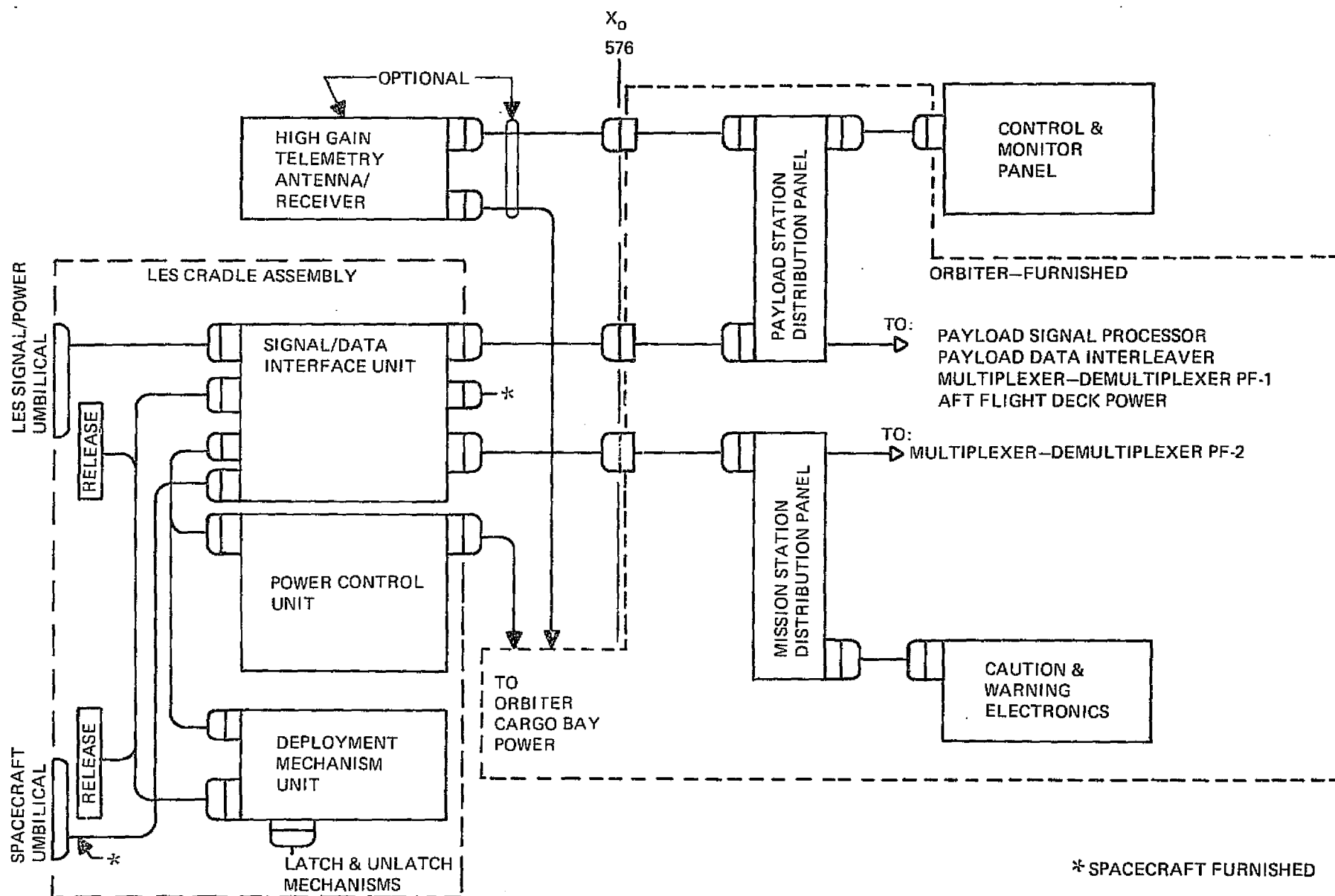


FIGURE 8.5 AVIONICS AIRBORNE SUPPORT EQUIPMENT AND CABLING DIAGRAM

and cabling interface approach for Orbiter installation. This approach uses the Orbiter payload accommodates equipment where practical with additional equipment added and interfaced for functional operation and deployment of LES. In addition, provisions for physical and functional interface of selected caution and warning candidates were incorporated for monitoring for safe conditions of Orbiter payload with control circuitry for safing in the event of an unsafe condition prior to deployment. These ASE and Orbiter installed avionics satisfy the STS physical and functional interface requirements.

If an "adaptation" of the LES to SSUS-D is needed for spacecraft not now in the LES payload model the SSUS-D cradles can be modified for this application. The modification includes the addition of signal, power and deployment interface units and removal of selected component parts not required for the "adaptation." Since the SSUS-D/LES combination will not be spin stabilized, deletion of spin physical and functional interfaces will be by procedural changes. Figure 8.6 shows one of these combinations as installed in the SSUS-D cradle.

8.1.2.4 Ground Support Equipment - Ground support equipment identified in Table 8-IV provides major items of checkout, handling, transporting, servicing and miscellaneous support equipment for both the factory and field. These support equipment provide the capability to physically and functionally verify stage systems from acceptance through assembled level tests. The handling, transporting and servicing equipment provides the capability to physically and functionally integrate four primary interfaces. These are:

- o LES/Cradle Assembly
- o LES/Spacecraft
- o LES-Spacecraft-Cradle Assembly/ETR or WTR
- o LES-Spacecraft-Cradle Assembly/Orbiter

8.2 GROUND AND FLIGHT OPERATIONS

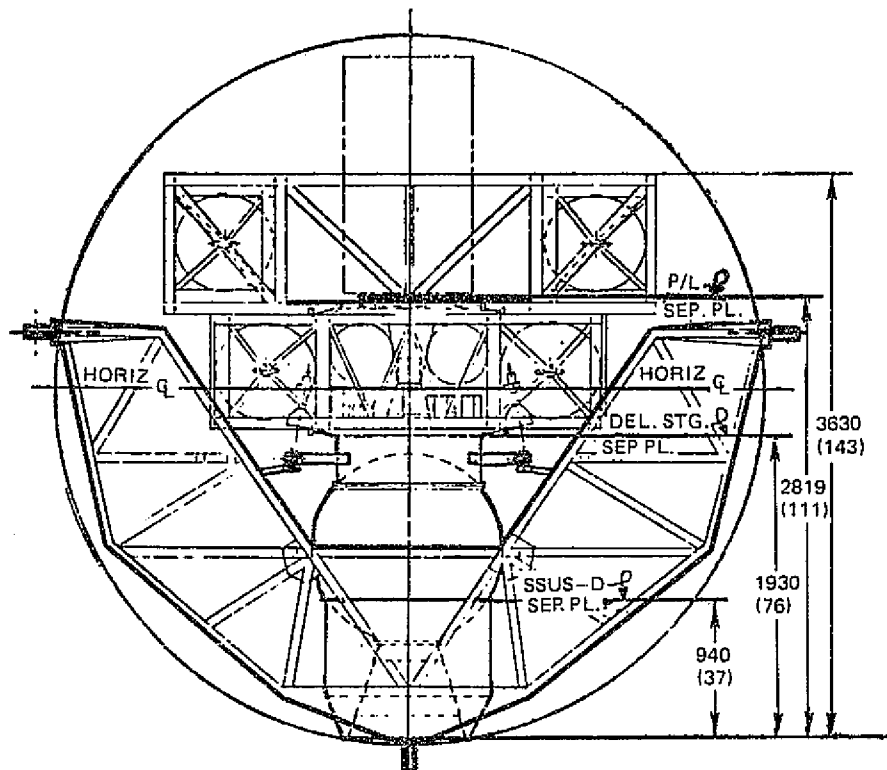
Ground and flight operational requirements including functional task flows, timelines, support equipment, facilities, and personnel were established for the LES and its ASE in Volume III, paragraph 6.0. Operations at the launch site include receiving, inspection, assembly and interface tests, range and status verification. The approach developed provides an

DIMENSIONS IN MILLIMETERS (INCHES)
WEIGHT IN KILOGRAMS (POUNDS)

TOTAL ASE WEIGHT FOR VERTICAL
SSUS-D = 1021 (2250)

NOTE: SSUS-D VERTICAL CRADLE

REQUIRES: 2184 + 152 CLEARANCE = 2336 OF CARGO BAY LENGTH
(86) + (6) CLEARANCE = (92) OF CARGO BAY LENGTH



4 TANK MODULAR BI-PROPELLANT LES/SSUS-D
MOUNTED IN SSUS-D CRADLE

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FIGURE 8.6 VERTICAL LES/SSUS-D ADAPTATION INSTALLATION

TABLE 8-IV SUPPORT EQUIPMENT

ITEM	DESCRIPTION	FACTORY REQMT	FIELD	
			REQMT	REF. FIG. 6.4 TASK NUMBER
	<u>CHECKOUT</u>			
1	Guidance and Control Test Set	X	X	8.0
2	TDY-43 Computer Test Set	X	X	8.0
3	Telemetry Test Set	X	X	8.0
4	Test Battery Simulator	X	X	8.0
5	Pyrotechnic Test Load Simulator	X	X	8.0
6	Thruster Test Load Simulator	X	X	8.0
7	Portable GHe Servicing Cart (with accessories)	X	X	34.0; 5.0; 16.0
8	Audio GHe Spectrometer	X	X	34.0; 5.0
9	ASE/Avionics Simulator	X	X	36.0; 28.0; 29.0
10	Umbilical Simulator	X	X	37.0
11	Cables and Cable Plant	X	X	8.0; 15.0; 17.0
12	Electrical/Electronic Test Equipment	X	X	11.0; 26.0
13	Control and Monitor Panel		X	26.0; 17.0; 22
14	Electro Explosive Devices Test Equipment (GFE)		X	32.0; 11.0
	<u>HANDLING TRANSPORTING AND ASSEMBLY</u>			
15	Shipping Containers	X	X	1.0; 2.0
16	Mobile Flat Bed Assembly		X	35.0; 12.0; 13.0
17	Hoist Sling for Tanks	X	X	4.0
18	Turn Over Hoist Sling for LES	X	X	3.0; 6.0
19	Hoist Sling for Vertical Lift of Payload at the VPF		X	14.0
20	Fork Lift (GFE)		X	1.0; 2.0
21	Truck (GFE)		X	12.0
22	Cradle Assembly		X	35.0
23	Multi-Mission Support Equipment (GFE)		X	14.0; 19.0; 20.0; 21.0
24	Hoist Sling for LES	X	X	1.0
25	LES Handling/Assembly Dolly	X		
26	Hydroset	X	X	4.0
	<u>MISCELLANEOUS</u>			
27	Hand Tools	X	X	All as Required
28	Safety Equipment	X	X	As Required

X - ONE EACH REQUIRED OR AS NOTED

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efficiently controlled processing and launch preparation capability. Flight operations scoped and delineated include monitoring of the LES, its ASE, and payload from Shuttle launch through predeployment tests, deployment and orbital transfer to payload separation. Flight sequence begins at deployment and ends with payload separation from the LES. Telemetry coverage is to be provided throughout the flight sequence.

Ground support equipment used in field operations includes guidance, control, computer, electrical, electronic, and telemetry test sets; pyrotechnic, avionics, electrical, ASE, umbilical and thruster simulators; cable plant; and control monitor panel. Handling, transporting, and assembly equipment includes a mobile flat bed assembly used to assemble the stage, cradle, and payload and to transport this assembly, hoist and turnover slings, dollies, tools and safety equipment.

An evaluation of functional task flows and resulting timelines relative to Shuttle field operations timelines resulted in the definition of a field team manned with proper personnel and skills of 18. These personnel include supervisory, administrative, inspection, quality and logistics specialists as well as engineers and technicians. A field team is required at EPR in late 1981 and at WTR in 1983. It is envisioned that these teams could provide field support for all Shuttle low energy upper stages.

Additional program management, supporting engineering, logistics, inspection and quality personnel are required at the LES manufacturer facility on an annual and per stage basis.

8.3 IMPLICATIONS OF SHUTTLE USER CHARGE

Implications of Shuttle user charge policy as defined in published STS documentation, as well as some recommended changes and additions are as follows:

- The keying of Shuttle user charge to payload length or weight tends to drive payloads to low weight, short lengths, and large diameters when installed horizontally in the Orbiter cargo bay.
- Orbiter cargo weight-to-length equivalence in user charge is shown in the following table.

LAUNCH SITE	ORBIT INCLINATION DEG	WEIGHT-TO-LENGTH RATIO kg/m (lb/ft)
ETR	28.5	1612 (1083)
	56	1414 (950)
WTR	90	918 (617)
	98	818 (550)

Orbiter payloads with weight-to-length ratio greater than these pay according to weight; for lower ratios payment is according to length.

- Length critical Orbiter payloads should be installed vertically in the cargo bay if (1) the length of the spacecraft and stage exceeds the diameter of this combination as well as the bay length occupied by the ASE and if (2) the length of the spacecraft stage and ASE cradle combination is less than the cargo bay diameter.
- Airborne support equipment should not extend beyond payload-stage combination.
- Airborne support equipment which in rotating payload-stage combinations from horizontal to a deployable orientation require additional cargo bay length and incur additional user charge if length critical.
- The current charge policy for the use of OMS kits which includes length or weight charge, use charge, and serial time impact charge makes their use very unattractive.

- User cost charges for Orbiter delivery to altitudes and inclinations other than the standards should be defined. These standards as currently defined, are as follows:

<u>LAUNCH SITE</u>	<u>ALTITUDE km (nm)</u>	<u>INCLINATION DEG</u>
ETR	296 (160)	28.5° & 56°
WTR	296 (160)	90° & 104°

- The 487 STS payload model has no payload destination orbits at 104° inclination. Most orbits at inclinations greater than 90° are near sun-synchronous which, for the altitudes specified, are grouped around a median inclination of 98°. Consideration should be given to changing the 104° standard orbit to 98°.
- The charge policy to a shared flight user for a non-standard orbit on a flight in conjunction with other standard orbit users should be defined.

8.4

IMPLEMENTATION PLANS

Implementation plans for the recommended approach to accommodate the LES payload mission model have been developed to support future NASA program decisions.

Implementation plans for the Shuttle with use of integral OMS fueled to deliver payloads to orbit are defined in STS documentation. Clarification of charge policy for shared flight users to non-standard orbits should be made.

Operation of the Scout launch vehicle should be continued from the San Marco launch site through 1982 to launch the two San Marco payloads and the two AMPTE payloads scheduled in 1980 through 1982. This operation should be continued beyond 1982 if additional new payloads require low altitude or elliptical orbits (non-geosynchronous) before the Shuttle, with a low energy upper stage, is operational from ETR. The Scout launch vehicle should continue operation from WTR into 1983 until the Shuttle, with a low energy upper stage, is operational from WTR. Scout implementation plans are contained in NASA Scout documentation.

Implementation plans for the new low energy stage system including development, manufacturing, integration and test requirements, cost and schedule projections, and a definition of the operational data are presented in the following paragraphs of this section.

8.4.1 Requirements

Development, manufacturing, integration and test requirements are defined consistent with schedule and cost projections.

8.4.1.1 Development - The plan for development consists of an integrated combination of prime contractor equipment, facilities, procedures, and personnel to perform the program segments of design, procurement, fabrication, assembly, testing, checkout and delivery of the LES. The key program philosophy assuring integrity of schedule and cost projections includes:

- The structural ultimate and yield design and proof test factor of safety will permit the use of the ASE structural test article and the airframe vibration test article in the deliverables.
- Design requirements and margins will be established to maximize the use of off-the-shelf hardware or designs with minimum modification.
- Off-the-shelf hardware or qualified design will be used wherever possible. The categories listed in order of priority are: In production with no mod, production with mod, designed and qualified but out of production with no mod and then with mod, and lastly, new design with prototype and qualification testing.
- Subcontractor to be used for component test with prime contractor accomplishing subsystem, system, and full scale tests.

The major tasks considered for LES, GSE, ASE and Operations for program schedule and costs projections are:

- Definition of System Requirements; e.g. performance, safety, reliability, maintainability, environmental, schedules, groundrules and statement of work.

- System Trade Studies; e.g. preliminary design, specifications, checkout concept, maintenance concept, ground operations flows, facilities requirements, program plans, test requirements, mission operations, software requirements, subcontractor negotiations, internal interface requirements identification, schedules, controls, high risk items, handling, and work breakdown structure.
- Detail Design; e.g. drawings, system and subsystem design integration, plans, specifications, procedures, component performance, and analysis reports.

8.4.1.2 Manufacturing - LES is a truss structure design assembled by the use of weld joints and attachments, Figure 8.7. Figure 8.8 depicts the detail fabrication, subassembly, assembly, checkout and final acceptance of LES. Dummy tanks are used in the factory processing because the propellant tanks are manufactured, tested, serviced, sealed and shipped direct to the field site for LES installation. The tanks are a single expulsion cycle design.

The program schedule and cost projections for LES, GSE, and ASE were based on the following major tasks:

- Fabrication of Details - structure, cradle and GSE
- Assembly - structure, cradle and GSE
- Installations - plumbing, cabling, propellant tanks, rocket motors, guidance equipment, electrical equipment, separation equipment, telemetry equipment and pressurization equipment
- Test and Checkout - component acceptance, bench test, and assembled tests

8.4.1.3 Integration - The LES is a part of the payload for the Shuttle flight and a launch vehicle to deliver the spacecraft from the Shuttle orbit to the mission operational orbit. Therefore, control and verification of many interfaces is necessary to assure a successful mission. These interfaces are internal to the LES, GSE, and ASE designs and external between

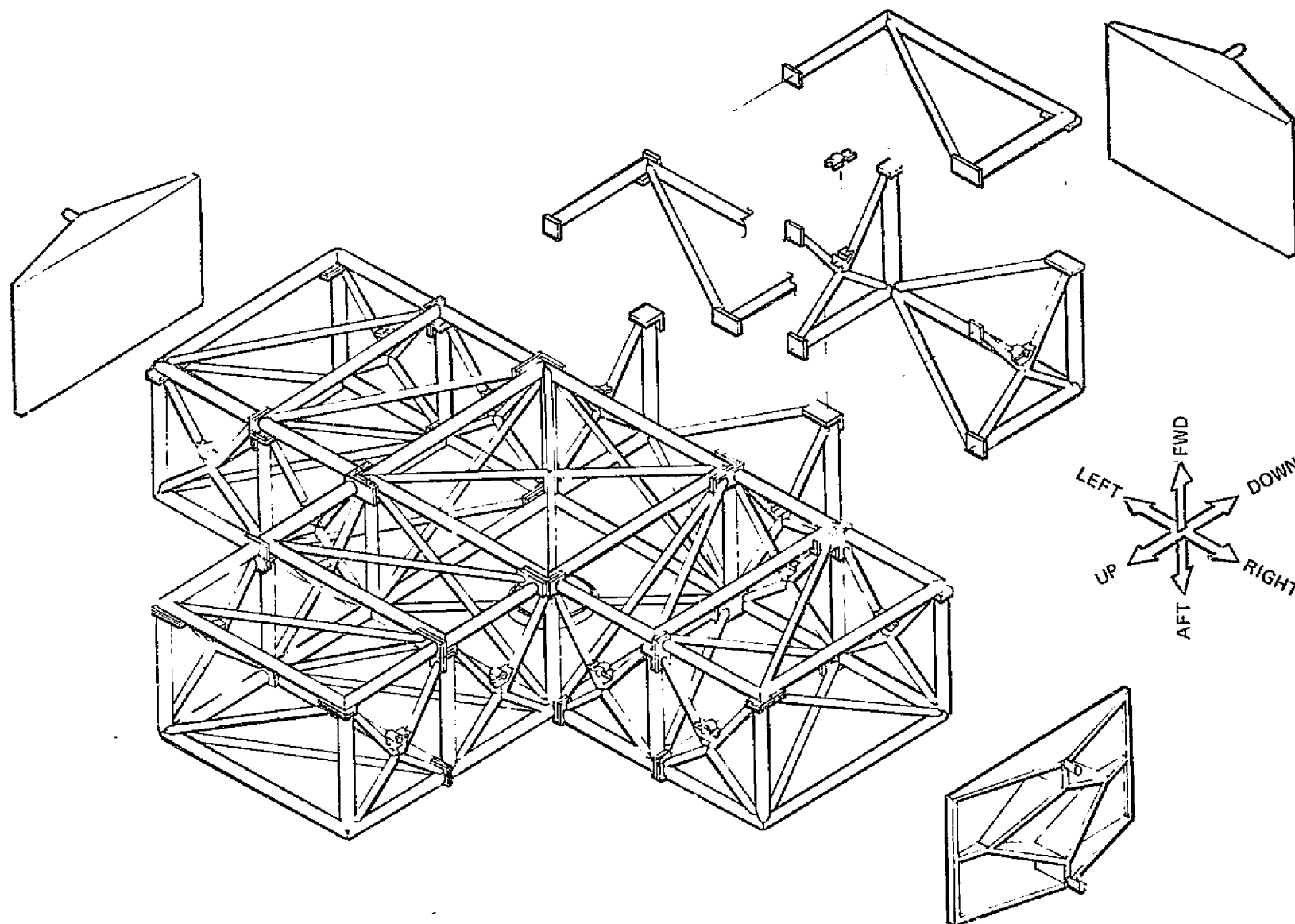


FIGURE 8.7 LES MODULAR STRUCTURE

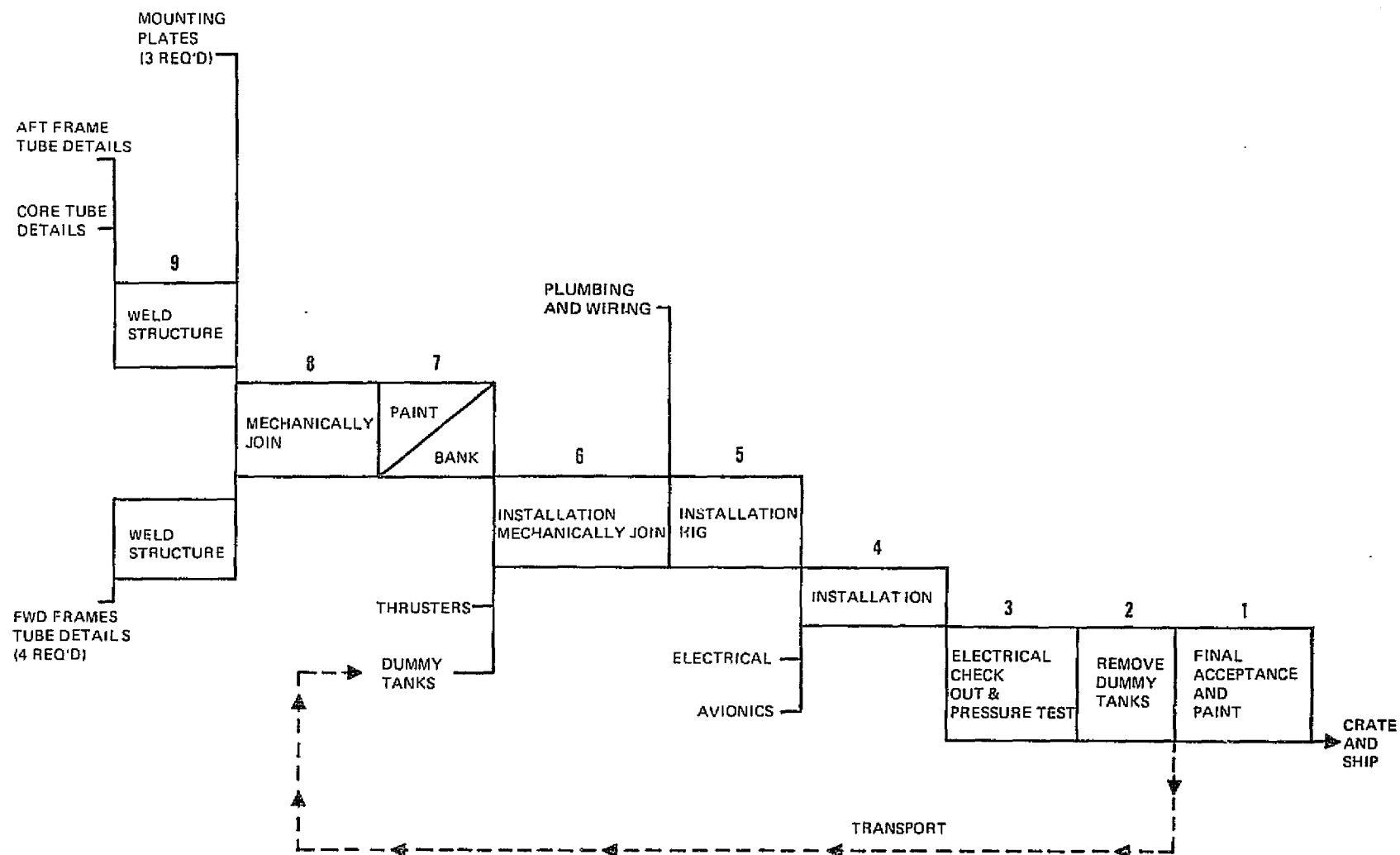


FIGURE 8.8 LOW ENERGY STAGE MANUFACTURING STATION CHART

LES/Shuttle, LES/Shuttle Support Facilities, LES/GSE, LES/ASE, LES/Spacecraft, transportation, handling and personnel.

The integration effort provides the means for monitoring and control of the execution of the LES program to assure system performance and schedule progress are consistent with cost expenditure. Some of the major tasks covering the LES, GSE, ASE and external interfaces are:

- Design Integration - inter and intra interface control documentation, simulations, trade studies, spares, traceability, comparison of test results against design objectives, trend data, sequencing, mission profiles, contingency plans, groundrules and guidelines, constraints, major level requirements, functional flows, risk analysis, major hardware selection, coordinated top level test plan, and change control board
- Fabrication - flow/design integration, tool development, and assembly/installation flow
- Test - approve all detail test plans and procedures, test readiness reviews, conduct post test reviews (hardware and analysis), hardware disposition, conduct malfunction investigation, monitor corrective action cycle, and reports
- Pre-Delivery - coordinated top level test and checkout plan, discrepancy corrective action review, readiness reviews, change traffic, final buy-off, and packing and shipping procedure
- Operations - Operations plan, training plan, site activation plan, safety procedures, transportation and handling plan, demonstration plan covering all the inter and intra physical/functional interfaces, demonstration readiness and post reviews, and malfunction/discrepancy action

In support of this effort, both contractor supplied equipment and GFE are required. The GFE requirement consists of a fork lift, truck, Multimission Spacecraft support equipment, Shuttle Mock-up Access and Launch

Site assembly and checkout facilities area.

8.4.1.4 Test - The test program includes development, qualification, acceptance, prelaunch, and flight. The philosophy is:

- (a) The test program shall be controlled by the use of test plans and procedures. All development test plans and procedures will be approved by the contractor and submitted to the NASA contracting agency for information. All qualification plans and procedures will be submitted to the NASA contracting agency for approval.
- (b) Component testing will be accomplished by the subcontractors. The LES contractor will accomplish all subsystem, system, and full scale testing.
- (c) System simulation analysis will be used to aid engineering judgment in the definition of a test program that provides data for evaluation of critical characteristics and trends.

The execution of the program is shown in Figure 8.9 which depicts the following key activities:

- (a) Correlation between requirements and tests through a test requirements matrix.
- (b) Development of approved test plan.
- (c) Planning and coordination of each test.
- (d) Test readiness and post test reviews with NASA participation.
- (e) Test operations conducted with close quality assurance and configuration control.
- (f) Data analysis.
- (g) "Closed-loop" verification process to ensure requirements and specification or contract compliance.

The development phase is an 11 month effort. The qualification and Stage/Ground Support Equipment/Aerospace Support Equipment demonstration phase is a 9 month effort.

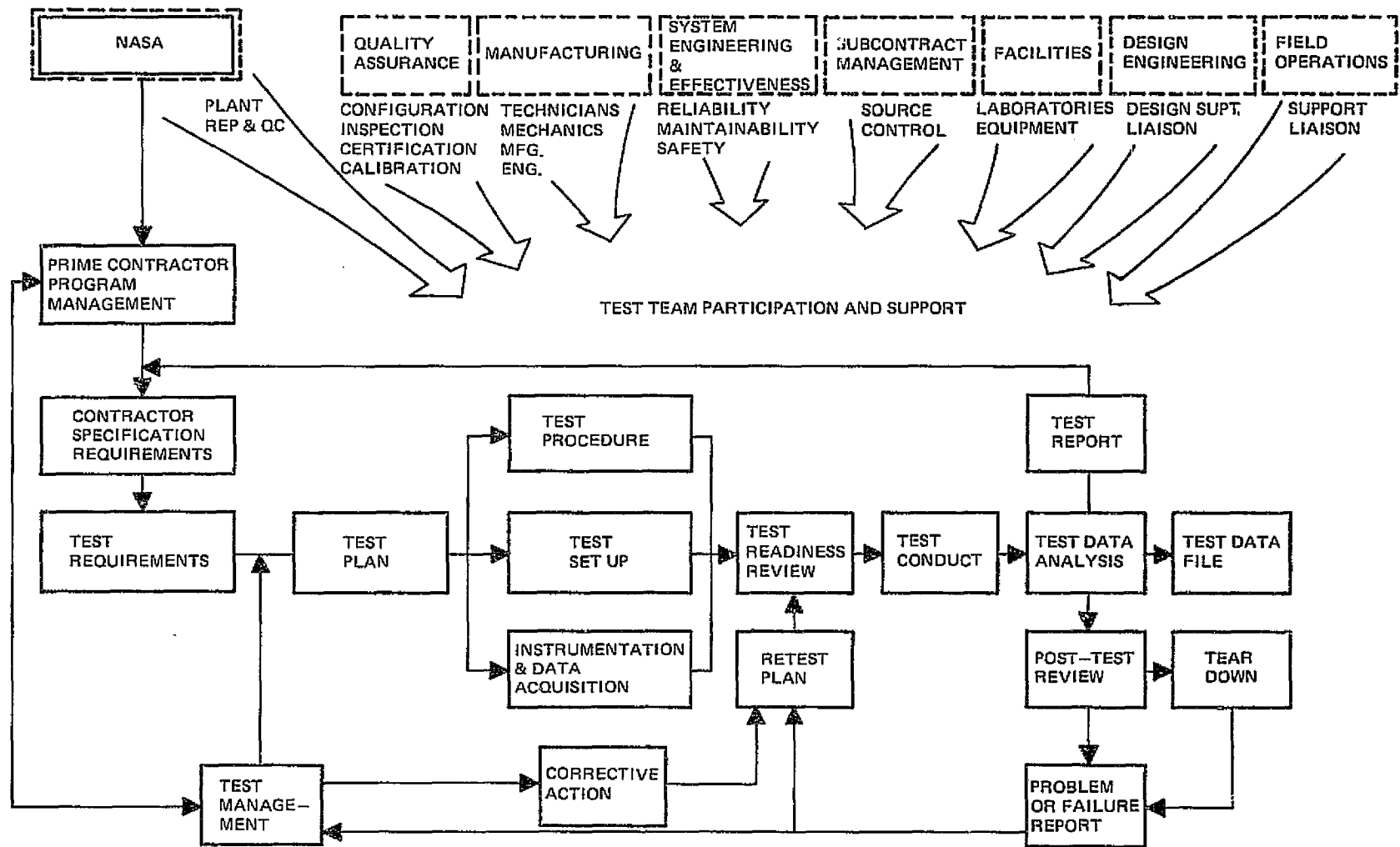


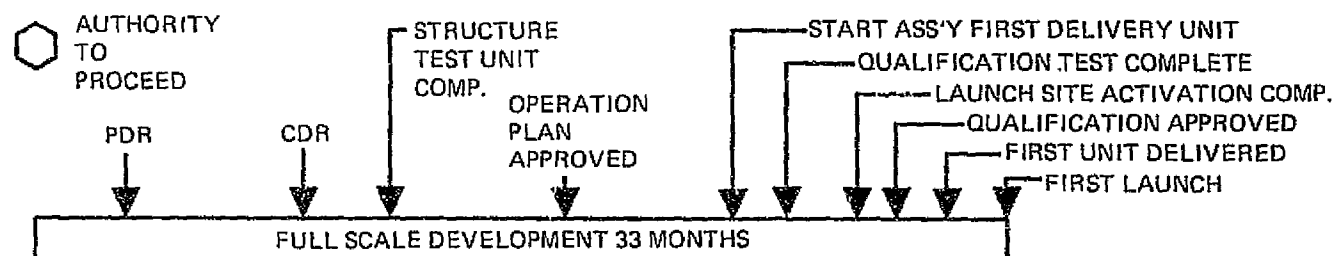
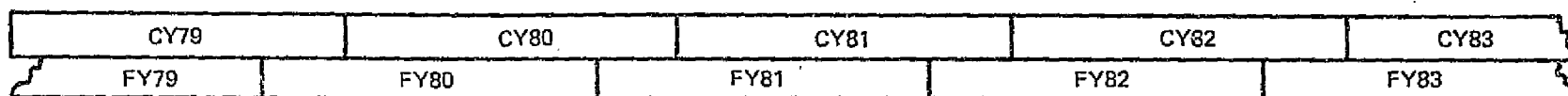
FIGURE 8.9 TEST FLOW

The schedule and cost projections for the test phase of the LES, GSE and ASE component, subsystem, system and complete stage are based on the following major tests:

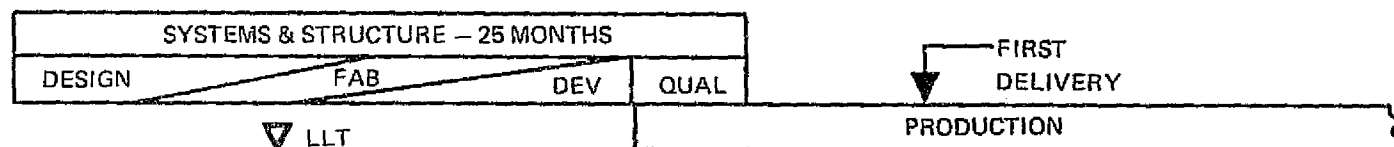
- Development Test - tankage, loads, propellant servicing and expulsion, leakage, verification of procedures, sequencing, reliability, evaluation of critical environments, software, performance control, force dynamics, thermal, full scale hot firings, complete system test, electrical/electronic system evaluation, separation, cargo bay ejection, and handling demonstration
- Qualification Test - performance, software, environmental (thermal, pressure, vacuum, vibration, acoustic), control dynamics, loads, reliability, combined environments, validate procedures, and safety
- Pre-Delivery - component acceptance, bench test, assemblies, and simulated launch
- Demonstrations - handling and transportation, interface and functional validation of LES/GSE/ASE/Spacecraft/Shuttle (mock-up), validate procedures, software and launch crew (ground and orbit), validate site, and complete launch site flow and time line validation
- Pre-Flight - system test and checkout, cargo bay integrated test and pre-flight readiness test

8.4.2 Schedules

The LES development program is 33 months from full scale development start to first launch. Recommended start date is fiscal year 1980 (Oct. 1979) with first launch from the Shuttle in the third quarter of fiscal year 1982 (June 1982). A summarized schedule for each of the major segments of the program elements - Low Energy Stage, Airborne Support Equipment, Ground Support Equipment and Operations - is shown in Figure 8.10. The schedule provides for design trade studies, subsystem and system design and



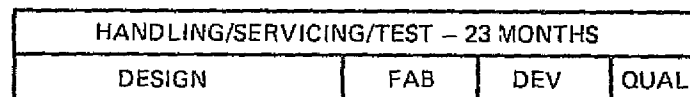
LES



ASE



GSE



OPERATIONS

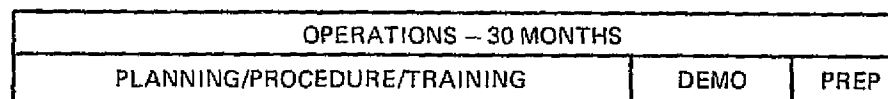


FIGURE 8.10 LOW ENERGY STAGE SYSTEM DEVELOPMENT SCHEDULE

development, production, operations, and verification of the flight vehicles. The major development effort is the system design integration and associated validation test. Further discussion of the LES design, development, test, and evaluation effort for the schedule elements can be found in Volume III, paragraphs 4.0, 5.0 and 6.0.

To achieve the best production cost break, the delivery schedule is based on building the LES in 20 unit production quantities. These are checked out and delivered over a 2 year time span.

A delivery schedule (Table 8-V) for the Low Energy Stage system shows delivery of 76 4-tank horizontal, 13 8-tank horizontal, and 14 4-tank vertical versions for a total of 103 stages between 1982 and 1991. There are 16 payload flights that use integral OMS for non-standard orbits. The Scout launch vehicle launches 10 payloads. Total number of flights is 129 - the number of flights in the LES payload mission model.

8.4.3 Operational Date

With scheduled validation of stage/ASE/GSE/Shuttle interface compatibility in late 1981, field site activation in late 1981 and field site demonstration in early 1982, and delivery of first production unit of the low energy stage system in May 1982, the initial operational date is June 1982. While the low energy payload model schedule is structured to require only the 4-tank horizontal version of the low energy stage system in 1982, implementation plans have been defined to provide the delivery of both 8-tank horizontal and 4-tank vertical versions in 1982. The launch schedule of the payload model requires these latter two versions in 1983. Should future payloads (not now defined) appear with mission requirements in the low energy regime beyond the capability of the 8-tank version, the spacecraft development lead time (based on current experience) would exceed the time required to adapt a 4-tank vertical version of the low energy stage system as a delivery stage above a SSUS-D used as a booster stage. Thus, this adaptation would be available in time to deliver the spacecraft to its required orbit.

8.4.4 Cost Summary

The cost to deliver the Low Energy Stage Payload mission model

TABLE 8-V LOW ENERGY STAGE SYSTEM DELIVERY SCHEDULE

LAUNCH SITE	STAGE	CALENDAR YEAR										TOTAL
		'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	
ETR	4-Tank Horizontal	4	1	2	3	2	3	1	3	2	2	23
	8-Tank Horizontal						1		1			2
	4-Tank Vertical		1				1		1		1	4
WTR	4-Tank Horizontal		4	3	6	5	7	7	6	7	8	53
	8-Tank Horizontal		1		1	2	1	2	1	2	1	11
	4-Tank Vertical		1	2		1	1	1	1	1	2	10
	<u>TOTAL</u>											
	4-Tank Horizontal	4	5	5	9	7	10	8	9	9	10	76
	8-Tank Horizontal		1		1	2	2	2	2	2	1	13
	4-Tank Vertical		2	2		1	2	1	2	1	3	14
												<u>103</u>

SUMMARY

INTEGRAL OMS

Non-standard Orbit	16
Scout	10
LES System	<u>103</u>
LES Model	129

with the recommended approach (Figure 8.11) shows the costs expended during each year from 1979 through 1991. These costs are for the delivery of 16 payloads with Shuttle integral OMS, 10 payloads with Scout, and 103 payloads with the LES system. For the 16 payloads delivered to non-standard Shuttle orbits, the costs include the shared flight user charge for the payloads and a \$200,000 special orbit charge. Scout costs to deliver the 10 payloads include a unit charge per launch and an annual Scout program maintenance cost. Costs to deliver the 103 payloads by the LES system include Shuttle shared flight user charge for the payload, stage, and ASE; LES design, development, test and evaluation (DDT&E) costs; LES production costs; and LES operations costs. These operations costs include annual sustaining costs, flight dependent costs, and annual field teams costs. The cumulative total cost is \$1482.1 in millions of 1977 dollars made up of \$283.7M for integral OMS, \$57.6M for Scout, and \$1140.8M for the LES system. The cumulated annual costs in 1977 dollars discounted at a 10% discount rate is shown in Figure 8.12, and the present value cost (1977) to deliver the total LES payload model is \$507.8M.

A funding schedule for the LES system that does not include Shuttle user charge is shown in Table 8-VI in 1977 dollars. The schedule shows DDT & E, production, and operations costs as well as the total for each year. Total funding in millions of dollars is \$266.5. These costs are also shown discounted at 10% to 1977; the present value of the total funding is \$112.9M. The costing methodology, ground rules, cost estimating relationships as well as detail build up of costs from level 5 (where applicable) of the LES work breakdown structure to support these summary cost data are in Volume V, Program Study Cost Elements, of this report.

8.5 ADDITIONAL RECOMMENDATIONS

Based upon the analyses and evaluations performed in this study and emerging Shuttle payload requirements the following additional recommendations are made:

- (1) Consideration should be given to the applicability, modifications required, and potential cost benefits of extending the modularity in the recommended LES system to produce the capability:

INCLUDES DDT&E, PRODUCTION, AND OPERATIONS COSTS
AND SHUTTLE CHARGE FOR STAGE, ASE, AND PAYLOAD

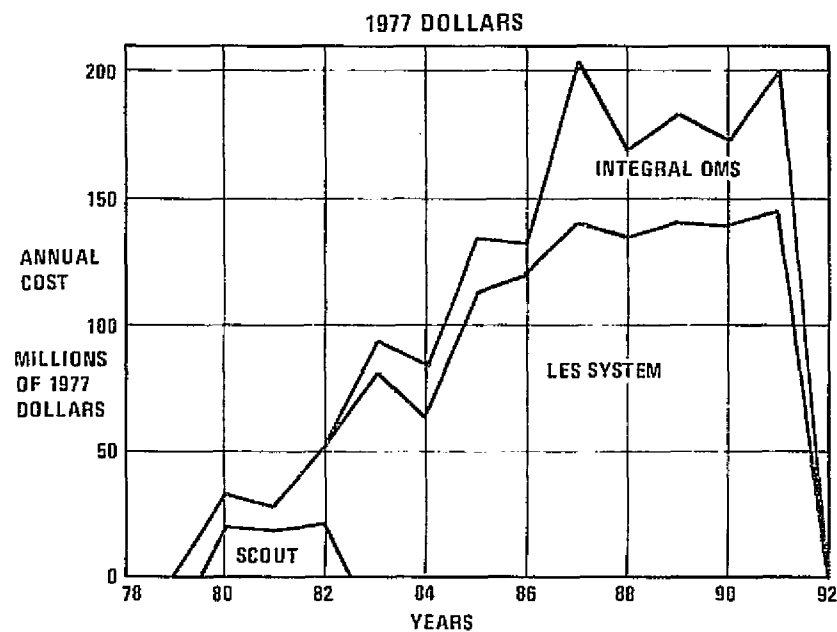


FIGURE 8.11 COST TO LAUNCH LES PAYLOAD MODEL

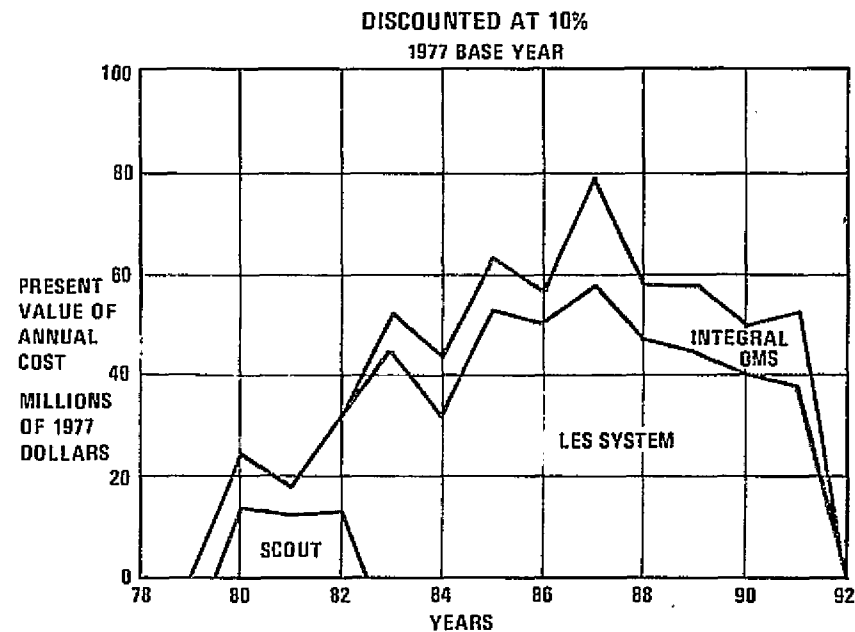


FIGURE 8.12 DISCOUNTED COST TO LAUNCH LES PAYLOAD MODEL

TABLE 8-VI FUNDING SCHEDULE FOR LES SYSTEM

THOUSANDS OF 1977 DOLLARS

	YEAR													
	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
DDT & E	1,303	14,620	9,136	1,045										26,104
PRODUCTION				7,026	14,462	12,326	17,944	18,337	25,379	20,093	23,621	21,849	25,016	186,053
OPERATIONS				2,941	4,801	4,490	5,422	5,422	6,664	5,734	6,352	6,043	6,665	54,534
TOTAL	1,303	14,620	9,136	11,012	19,263	16,816	23,366	23,759	32,093	25,827	29,973	27,892	31,681	266,692

- (a) to function as a spacecraft propulsion unit for transfer to the destination orbit and to provide attitude and orbit control propulsion for the spacecraft throughout its life.
 - (b) to function as a retrievable upper stage to return to the Orbiter after spacecraft delivery for refurbishment, refueling and reuse from the Shuttle orbit or from the earth.
 - (c) to function as an upper stage to deliver a spacecraft to its destination orbit and later, to return the spacecraft to the Shuttle for refurbishment and reuse. In this application the LES system stage should be considered to provide transportation only or transportation and destination orbit support. The options to refurbish the spacecraft and stage and reuse from the Orbiter or from the earth should be evaluated.
- (2) Consideration should be given to the development of a modular interface kit capability for physical and electronic mating with a broad spectrum of spacecraft.

9.0 SUPPORTING RESEARCH AND TECHNOLOGY REPORT

A prime objective in the performance of the Low Energy Stage Study contract was to maximize the use of already developed hardware and technology. The recommended LES System is based on technology that is already developed. Consequently, there were no new research or technology items defined in the course of the study.

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